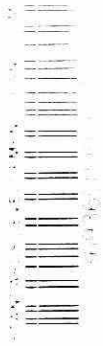

Sludge Metal Solubilities in Soils

Research Report No. 76

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Research Program for the Abatement of Municipal Pollution under Provisions of the Canada-Ontario Agreement on Great Lakes Water Quality

CANADA-ONTARIO AGREEMENT

RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies being carried out in this program through in-house projects by both Fisheries and Environment Canada, and the Ontario Ministry of Environment, and contracts with municipalities, research institutions and industrial organizations.

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Sludge metal solubilities in soils
/ Webber, Melvin D.

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SLUDGE METAL SOLUBILITIES IN SOILS

by

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AGRICULTURE CANADA

RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION UNDER THE
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ABSTRACT

Eight anaerobically digested Ontario sewage sludges, including two lime, four ferric chloride and two without P-removal chemicals were mixed with six soils and incubated in the laboratory under a variety of simulated field conditions. The sludges exhibited a wide range of metal contents and the soils a wide range of chemical and physical properties. Following incubation, the sludge-soil mixtures were extracted with 0.005M DTPA, 0.5N HOAc, 0.05M EDTA and 0.01M $CaCl_2$ to measure Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn solubilities, and with acid ammonium oxalate, 1N $(NH_4)_2CO_3$ and 0.02M KCl to measure Mo solubility. In addition, columns of soils limed to pH 7 and treated with sludges were leached with 0.02M KCl to determine the potential for Mo movement.

Adding sludge increased the levels of extractable Cd, Zn, Cu, Ni, Pb and Mo in soils in relation to the amounts of metals added. The sludges contained small amounts of Co and caused no consistent changes in extractable Co, while Cr and Sn were not detected in any of the extracts. DTPA-extractable Zn, Ni, Pb and Co increased with increasing organic matter contents of the soils whereas DTPA- and HOAc-extractable Zn decreased with increasing clay contents.

Incubating sludge-soil mixtures under a variety of simulated field conditions indicated that the levels of extractable metals were largely independent of weather conditions likely to occur in Ontario. They were approximately the same following incubation at -15°C, 10°C, 25°C, and alternate -15°C and 25°C. Anaerobiosis generally reduced metal solubilities but is unlikely to occur widely under field conditions. Liming reduced the levels of DTPA-extractable Zn and Ni but not of Cu, Pb or Cd. Adding a large amount of newspaper to the sludge-soil mixtures caused little if any change in metal solubilities. Repeated applications of sludges containing large amounts of metals caused very high levels of extractable metals.

Leaching removed Mo from sludge treated soils and the loss was most rapid from the soil with the lowest clay and organic matter contents. No Cd was detected in the leachates.

Land application of Ontario sewage sludges will increase the solubilities of many heavy metals in soils and uncontrolled application of sludges containing large amounts of these metals will cause excessive increases. High metal solubilities in soils are likely to cause crop and animal toxicities; however, further work is required to define the critical levels. Molybdenum leached slowly from soils adjusted to pH 7 and high levels of that metal are not expected to persist in agricultural soils.

RÉSUMÉ

Huit types de boues digérées en milieu anaérobie, en Ontario, ont été mélangés à six types de sols et incubés en laboratoire dans des conditions naturelles fort diverses. Deux de ces types de boues étaient traités à la chaux, quatre au chlorure ferrique et deux exempts de produits chimiques de déphosphatation. Les boues présentaient un large éventail de teneurs en métaux et les sols, des propriétés physiques et chimiques très variées. Après incubation, les mélanges de boues et de sols ont été soumis à des extractions au DTPA 0,005 M, HOAc 0,5 N, EDTA 0,05 M et $CaCl_2$ 0,01 M, pour mesurer la solubilité du Cd, Zn, Cu, Ni, Pb, Co, Cr et Sn, et à l'oxalate acide d'ammonium $(NH_4)_2CO_3$ 1 N et au KCl 0,02 M, pour mesurer la solubilité du Mo. De plus, des colonnes de sols dont le pH avait été ajusté à 7 par addition de chaux et auxquelles on avait ajouté les boues ont été soumises à une percolation par KCl 0,02 M afin de déterminer le potentiel de déplacement du Mo.

L'addition de boues a augmenté les teneurs en Cd, Zn, Cu, Ni, Pb et Mo extractibles dans les sols, proportionnellement aux quantités de métaux ajoutées. Les boues ne contenaient que peu de Co et n'ont pas provoqué de changements importants dans les teneurs en Co extractible. On n'a pas décelé nulle trace de Cr et Sn dans aucun des extraits. Les teneurs en Zn, Ni, Pb et Co extractibles au DTPA ont augmenté avec l'accroissement des teneurs en matière organique des sols, tandis que la teneur en Zn extractible au DTPA et à l'HOAc diminuait quand la teneur en argile augmentait.

L'incubation des mélanges dans diverses conditions naturelles simulées a indiqué que la teneur en métaux extractibles est largement indépendante des conditions météorologiques qui se rencontrent en Ontario. Cette teneur était demeurée presque inchangée après des incubations à -15°C, 10°C, 25°C et à des températures alternées de -15°C et de 25°C. L'anaérobiose réduit généralement la solubilité des métaux, mais il est peu probable qu'elle se produise à grande échelle dans des conditions naturelles. Le traitement à la chaux a réduit les teneurs en Zn et Ni extractibles au DTPA, mais non pas celles en Cu, Pb ou Cd. L'addition de grandes quantités de papier journal aux mélanges de boues et de sols n'a

que très peu affecté la solubilité des métaux. Des applications répétées de boues contenant de grandes quantités de métaux ont donné lieu à des teneurs très élevées en métaux extractibles.

La percolation élimine le Mo des sols additionés de boues et la perte est d'autant plus rapide que la teneur des sols en argile et en matière organique est plus faible. On n'a détecté aucune trace de Cd dans les percolats.

L'épandage des boues sur les sols ontariens y augmentera la solubilité de plusieurs métaux lourds. Elle sera excessive si l'épandage de boues contenant de grandes quantités de ces métaux n'est pas maîtrisé. Des taux élevés de solubilité des métaux dans les sols risquent de rendre ces derniers toxiques pour le bétail et les cultures; toutefois, il faudra entreprendre D'autres travaux pour déterminer les niveaux critiques. La percolation du molybdène des sols dont le pH est ajusté à 7 est lente; on ne s'attend pas à ce que des concentrations très élevées de ce métal subsistent dans les sols arables.

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CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

In this investigation, anaerobically digested Ontario sewage sludges were mixed with soils and incubated in the laboratory under a variety of simulated field conditions. Columns of sludge treated soils were leached to determine the potential for Mo movement. The main conclusions were as follows:

1. Land application of Ontario sewage sludges will increase the soluble quantities of many heavy metals in soils and uncontrolled application of sludges containing large amounts of heavy metals will cause excessive increases.
2. Molybdenum leached slowly from soils adjusted to pH 7, and high levels of that metal are not expected to persist in agricultural soils.

RECOMMENDATIONS

The main recommendations arising from this study are as follows:

1. Industries should be influenced to remove metals from their effluents before they enter the domestic sewer system.
2. Sludge use in agriculture should be controlled to minimize metal build-up in soils.
3. Current methods for using sludge in agriculture should be based on the best information available.
4. Field and greenhouse experiments with sewage sludges should (a) establish the levels of extractable metals that are toxic to crops, (b) determine the potential for loss of metals from soils and (c) establish whether leaching of Mo from field soils is similar to laboratory experience.
5. Animals and poultry feeding experiments should be done to determine toxic levels of metals in plant materials.

1 INTRODUCTION

Sewage sludge is a by-product of wastewater treatment processes and in Ontario approximately eight million tons of suspension containing an average of 4% solids are produced each year. Sludge treatment and disposal is considered to be the most costly phase of wastewater treatment and it has generally been accomplished by the least expensive method available with little attention to environmental impact (Black and Schmidtke, 1974). The most widely practised method involves anaerobic digestion followed by dumping into sanitary landfills, sludge storage lagoons or onto farmers' fields. Recently, however, the Ontario Ministry of Environment has adopted a Comprehensive Resource Recovery Program and initiatives have been taken to employ sludge in the production of agricultural crops.

Application to agricultural land is desirable because sludges exhibit fertilizer and soil conditioning properties; however, it involves risks because pathogenic organisms and phytotoxic materials such as synthetic organic compounds and heavy metals may gain access to the food chain. The pathogens and organics represent a hazard to soil fertility within weeks or months of sludge application, but are probably not a long term hazard because they die or decompose and disappear slowly from the soil. The heavy metals represent a long term hazard because they accumulate in the soil and persist indefinitely (Bates, 1972; Page, 1974). Some such as zinc, copper, cobalt and molybdenum are required in small amounts for normal plant and animal growth. Others such as cadmium, lead and mercury serve no biological function. Larger than normal amounts of any or all of these metals in soils may cause toxicities to plants and animals.

Although the fertilizer and soil conditioning properties of sludges are likely to provide short term gains in crop production, it appears that long term maintenance of soil fertility will require careful management of sludge application based on a knowledge of the metal contents of sludges, metal solubilities in sludge treated soils and crop responses to metals. Thus, the objectives of this study were: (1) to measure the solubilities of metals added to soils in sewage sludges and

(2) to determine whether molybdenum contained in sewage sludges would leach from soils adjusted to pH 7.

Sludge sources chosen included no chemical treatment for phosphorus removal, as well as lime and iron treatment. Soils were chosen to provide ranges of clay and organic matter contents. Sludge was mixed with soil in the laboratory and: (1) incubated moist for various periods of time under various conditions of temperature and aeration to simulate Ontario field conditions, and (2) leached with a neutral salt of approximately the soil solution concentration. In addition, a large amount of newspaper (high C/N ratio) was added to selected sludge-soil mixtures to determine its effect on metal solubilities. Newspaper is a major component of domestic garbage which is sometimes mixed or composted with sewage sludge prior to land application. Metal solubilities in the incubated mixtures were determined by extraction and molybdenum was measured in the leachates.

With the exception of molybdenum, metals were extracted from the sludge-soil mixtures with 0.005M DTPA, 0.5N HOAc, 0.05M EDTA and 0.01M $CaCl_2$. The 0.005M DTPA has been used to assess the solubilities in soils of both nutrient (MacLean, 1974; John, 1972; Haq and Miller, 1972; Follett and Lindsay, 1971; Brown et al, 1971) and non-nutrient metals (Bingham et al, 1975; Webber and Gaynor, 1974). Evidence indicates that the DTPA-extractable metals are generally related to plant availabilities; however, the relationships may be improved by considering soil properties. For example, zinc concentration in corn was related to DTPA-zinc and soil pH below 7.0 (Haq and Miller, 1972) and in corn, lettuce and alfalfa to DTPA-zinc, soil organic matter content and pH (MacLean, 1974). In Britain, 0.5N HOAc is used on a routine basis to measure plant availabilities of a wide variety of metals except for copper which is measured with 0.05M EDTA (Mitchell, 1964) and both reagents have been used to identify metal contamination of soils (Webber, 1974; Beavington, 1973; Purves and Mackenzie, 1969; LeRiche, 1968). Moreover, Chumbley (1971) proposed that 0.5N HOAc be used to assess zinc and nickel availabilities and 0.05M EDTA be used to assess copper availability for regulating sludge application to soils. The

0.01M $CaCl_2$ is a neutral salt solution which approximates the concentration of soil solution and provides an index of metal solubility in the soil solution. MacLean (1974) reported that 0.01M $CaCl_2$-soluble zinc was related to plant uptake. Molybdenum was extracted from the sludge-soil mixtures with Grigg's Reagent, $1N(NH_4)_2CO_3$ and 0.02M KCl. A variety of extractants have been used in attempts to assess plant availability of molybdenum in soils but acid ammonium oxalate proposed by Grigg (1953) is the only one that has been extensively checked against field trials and used in advisory work (Davies, 1956). The $1N(NH_4)_2CO_3$ was recommended by Vlek and Lindsay (1977) who have used it to assess molybdenum availability in calcareous soils because it is alkaline and causes little dissolution of calcium carbonate. The 0.02M KCl is a dilute neutral salt solution which approximates the concentration of soil solution. It was used rather than 0.01M $CaCl_2$ to extract and leach soils because preliminary work showed that it removed marginally more molybdenum.

2 EXPERIMENTAL

Sewage sludges were mixed with soils and incubated moist in the laboratory. Extractable metals in the mixtures were measured at intervals during incubation.

2.1 Sewage Sludges

Eight anaerobically digested sludges were employed in the study including two without P-removal chemical from Fergus and Ottawa, two lime treated from Midland and Newmarket and four ferric chloride treated from Guelph, North Toronto, Sarnia and Stratford (Table 1). Whereas the Newmarket and North Toronto sludges were vacuum filter cake materials, the Ottawa sludge was obtained after drying for several months in a lagoon and the others were suspensions obtained directly from anaerobic digesters. Large quantities of the sludges were air-dried, ground with a Wiley mill and mixed to ensure homogeneity.

The sludges exhibited wide ranges of metal content (Table 1). Guelph and Sarnia contained high levels of cadmium (Cd); Fergus, Guelph and Sarnia, high zinc (Zn); Fergus, Guelph, North Toronto, Stratford and Ottawa, high copper (Cu); Midland, high nickel (Ni); Guelph, North Toronto and Sarnia, high lead (Pb); Fergus and Guelph, high chromium (Cr); Guelph and Stratford, high molybdenum (Mo); and Sarnia, high manganese (Mn). None of the sludges contained high levels of cobalt (Co), selenium (Se) or tin (Sn). The widely variable sludge metal contents reported in Table 1 are consistent with data reported by Page (1974) for sludges from several different countries.

The lime treated Midland and Newmarket sludges exhibited the largest calcium (Ca) contents; however, the level in North Toronto sludge was also elevated because lime was added prior to vacuum filtration. The ferric chloride treated Guelph, North Toronto and Sarnia sludges exhibited the largest iron (Fe) contents. None of the sludges contained large amounts of aluminum (Al) or magnesium (Mg).

TABLE 1. SELECTED PROPERTIES OF THE SLUDGES[1]

Sludge Identification	Cd	Zn	Cu	Ni	Pb	Co	Cr	Mo	Se	Sn	Mn	Al	Fe	Ca	Mg
	µg/g Sludge (70°C dry wt)											% (70°C dry wt)			
No P-Removal Chemical															
Fergus	23	9575	6118	219	352	5.3	3075	3	6.2	161	383	0.69	1.53	6.0	1.53
Ottawa	13	1811	1168	103	836	12.2	398	6	2.3	183	404	1.17	2.14	6.0	1.12
Lime Treated															
Midland	0.3	1305	377	2160	515	11.5	1153	2	1.1	84	378	1.12	1.20	13.9	0.91
Newmarket	1.7	572	185	13.0	90	ND	30	1	0.7	72	317	0.32	0.65	29.0	0.87
Ferric Chloride Treated															
Guelph	236	7040	3463	134	1670	10.0	4037	76	2.8	348	268	0.66	3.60	6.3	1.11
North Toronto	33	2603	1420	28	1950	11.5	910	19	2.8	368	559	1.38	8.40	9.7	0.59
Sarnia	99	10493	846	29	3269	6.9	168	6	3.8	355	2605	1.31	8.93	4.6	1.12
Stratford	62	2145	1270	952	632	NA	NA	1129	6.5	NA	NA	NA	NA	NA	NA

[1] The metals were determined by atomic absorption following aqua regia digestion (Van Loon and Lichwa, 1973). Se was determined fluorometrically following nitric-perchloric acid digestion (Levesque and Vendette, 1971).

ND = Not detected.

NA = Not available.

2.2 Soils

Large quantities of six soils were collected, air-dried, ground to pass a 2 mm screen and mixed to ensure homogeneity (Table 2). All were moderately to strongly acid with pH values in 0.01M $CaCl_2$ ranging from 4.3 to 5.4. The St. Thomas, Vaudreuil and Grimsby soils exhibited low clay contents and from 1 to 10% organic matter, whereas the Haldimand, Rideau and Wendover exhibited high clay contents and from 1.7 to 16.2% organic matter contents. The cation exchange capacities (CEC) were larger for the soils with high organic matter and clay contents. The Cd, Zn, Cu, Ni, Pb, Co, Cr and Mo contents were within the normal ranges for uncontaminated soils. These ranges have been defined as 0.01 to 0.7 µg/g Cd, 10 to 300 µg/g Zn, 2 to 100 µg/g Cu, 5 to 500 µg/g Ni, 2 to 200 µg/g Pb, 1 to 40 µg/g Co, 5 to 1000 µg/g Cr, and <0.2 to 5 µg/g Mo (Berrow and Webber, 1972).

2.3 Preparation and Handling of Sludge-Soil Mixtures

The mixtures were prepared with air-dried sludges, soils and finely shredded newspaper. The amounts of sludge were calculated on a 70°C dry weight basis. The materials were weighed into plastic containers and mixed thoroughly before distilled water was added and the containers closed. For moist, aerobic incubation the mixtures were maintained well moistened (not soggy wet) and were mixed and aerated at two-day intervals to maintain aerobiosis. Moist mixtures were frozen in a deepfreeze at -15°C. For the freezing and thawing treatment, mixtures were maintained at -15°C and 25°C during alternate weeks. Anaerobiosis was maintained by keeping the mixtures covered with approximately one-half inch of water. Anaerobiosis and aerobiosis were alternated at two-week intervals. Reagent grade calcium carbonate was added to the soils as required to produce pH 7.0 or to bring the sludge-soil mixture to a 10% calcium carbonate concentration. Following incubation the sludge-soil mixtures were air-dried, ground to pass a 2 mm sieve, and portions taken for analysis. Where appropriate, further increments of sludge were added to the dry mixtures, water added, and incubation continued.

TABLE 2. DESCRIPTION AND SELECTED PROPERTIES OF THE SOILS

Soil Identification		Sample Depth (cm)	Texture	pH[1]	Organic[2] Matter %	Sand[3] %	Silt[3] %	Clay[3] %
Low Clay Content								
St. Thomas	Humo-Ferric Podzol	0-30	Sand	5.2	3.1	91.1	6.8	1.3
Vaudreuil	Humic Gleysol	2-5	Sandy Loam	4.7	10.1	72.7	23.7	3.6
Grimsby	Grey Brown Luvisol	0-15	Silt Loam	4.3	1.0	43.7	48.9	7.4
High Clay Content								
Haldimand	Grey Brown Luvisol	0-15	Silty Clay Loam	4.8	4.0	11.3	52.3	36.4
Rideau	Glayed Eutric Brunisol	8-17	Silty Clay	5.3	1.7	5.7	49.1	45.2
Wendover	Melanic Brunisol	0-3	Silty Clay	5.4	16.2	6.7	47.9	45.4

Soil Identification	CEC[4] (meq/100g soil)	Total Metal (µg/g soil)[5]							
		Cd	Zn	Cu	Ni	Pb	Co	Cr	Mo
Low Clay Content									
St. Thomas	10.9	ND	68.0	8.3	17.3	35.8	8.8	45.3	0.35
Vaudreuil	18.4	0.5	49.8	6.5	15.5	38.0	8.0	49.0	0.55
Grimsby	10.4	ND	61.3	20.3	16.5	27.3	10.0	34.7	0.63
High Clay Content									
Haldimand	22.0	<0.5	94.3	15.0	26.8	42.5	17.3	63.3	0.77
Rideau	22.2	0.75	125.0	18.8	54.5	38.8	40.0	131.3	0.55
Wendover	34.7	ND	140.0	21.0	48.0	52.3	25.3	112.9	0.90

[1] Measured in a 1:2 (w/v) suspension of soil and 0.01M $CaCl_2$.
[2] Organic carbon determined with the Leco induction furnace was multiplied by 1.724.
[3] Determined by a pipette method after pretreatments with peroxide and citrate-dithionite bicarbonate (McKeague, 1976).
[4] The sum of exchange acidity determined with barium chloride triethanolamine (Peech, 1965) and exchangeable bases determined with normal ammonium acetate (Chapman, 1965).
[5] Determined by atomic absorption following hydrogen peroxide, nitric-hydrofluoric-perchloric acid digestion.
ND = Not detected.

Two sets of sludge-soil mixtures were prepared; one for the extractable Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn determinations and the other for the extractable Mo determinations. The Ottawa and Newmarket sludges contained very little Mo and sodium molybdate was added prior to mixing with soil, to give the same content as Guelph sludge (i.e., 76 µg Mo/g sludge).

2.3.1 Effects of mixing sludges and soils

The sludges (Table 1) were mixed with each soil at 2.5 g/100 g soil (Table 2) and incubated moist and aerobic at 25°C. The pH and DTPA, HOAc, EDTA and $CaCl_2$-extractable Cd, Zn, Cu, Ni, Pb, Co, Cr, Sn and acid ammonium oxalate, $(NH_4)_2CO_3$ and KCl-extractable Mo were determined after 42 and 84 days.

2.3.2 Effects of varying temperature, aeration and pH

The Ottawa, Newmarket, Guelph and Sarnia sludges were mixed with the Grimsby and Haldimand soils and incubated as follows: (a) -15°C, (b) 10°C, (c) 25°C, (d) 50°C, (e) alternate -15°C and 25°C, (f) alternate aerobic and anaerobic, (g) anaerobic, (h) calcium carbonate added to raise the soil pH to 7.0, and (i) 10 g calcium carbonate added to 90 g soil. Incubation was aerobic and at 25°C except as indicated. DTPA-extractable Cd, Zn, Cu, Ni, Pb, Co, Cr, Sn and acid ammonium oxalate, $(NH_4)_2CO_3$ and KCl-extractable Mo were determined after 84 days.

2.3.3 Effects of repeated sludge applications to soils

The Fergus, Midland, Guelph and Sarnia sludges were mixed with 100 g of each soil (Table 2) and incubated moist and aerobic at 25°C. DTPA-extractable Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn were determined after 42 days. Following the initial sludge addition and metal measurements, further 2.5% (w/w) increments of sludge were added and measurements taken at three intervals of 42 days. In addition to the 25°C treatment, the soils mixed with Sarnia sludge were incubated at 50°C.

2.3.4 Effects of sludge and newspaper applications to soils

The Guelph sludge (2.5 g) was mixed with 10 g of shredded newspaper and 90 g of each soil (Table 2) and incubated moist and aerobic at 25°C. The pH and DTPA-extractable Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn were determined after 84 days.

2.3.5 Leaching sludge-soil columns

Leaching studies were done to determine the potential for movement of sludge Mo through soils. Duplicate columns of the Grimsby, Haldimand and Wendover soils limed to pH 7 and treated with Guelph and Stratford sludges were prepared in sintered glass funnels (2.5 cm i.d.) and leached at room temperature with 0.02M KCl. The Haldimand soil was mixed 1:1 (w/w) with <1 mm quartz to increase its permeability. One hundred grams of soil or soil and quartz was placed in each column and the upper 35 g was mixed with 0.87 g of sludge (i.e., 2.5 g sludge/100 g soil). Leaching was done intermittently and under suction to maintain aerobiosis in the column and to increase the percolation rate. The volume and Mo concentration of the percolate were determined.

2.4 Analytical

The sludge and soil properties were determined as indicated by footnotes to Tables 1 and 2, respectively.

Acid washed glassware and deionised water were employed for all metal analyses. The Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn were extracted from the soils with DTPA, HOAc, EDTA and $CaCl_2$ at 25°C as follows: (a) 1:2 (w/v) soil and 0.005M diethylenetriaminepentaacetic acid (DTPA) in 0.01M $CaCl_2$ buffered with 0.1M triethanolamine at pH 7.3 was shaken for two hours (Lindsay and Norvell, 1969), (b) 1:20 (w/v) soil and 0.5N acetic acid (HOAc) was shaken for two hours (Chumbley, 1971), (c) 1:5 (w/v) soil and 0.05M ethylenediaminetetraacetic acid (EDTA) adjusted to pH 4 was shaken for one hour (Chumbley, 1971) and (d) 1:2 soil and 0.01M $CaCl_2$ was shaken for two hours. Molybdenum was extracted with acid ammonium oxalate $(NH_4)_2CO_3$ and KCl at 25°C as follows: (e) 1:10 (w/v) soil and acid ammonium oxalate was shaken overnight (Reisenauer, 1965),

(f) 1:2 (w/v) soil and 1N $(NH_4)_2CO_3$ was shaken overnight (Vlek and Lindsay, 1977) and (g) 1:4 (w/v) soil and 0.02M KCl was shaken for one hour. The extracts were centrifuged, filtered through Whatman No. 42 paper and the metals were measured by flame atomic absorption using standards prepared in the appropriate reagents. Molybdenum was complexed with benzoin α-oxime and concentrated in n-butylacetate (Lively, 1974) prior to measurement.

Dissolved organic matter in the acid ammonium oxalate $(NH_4)_2CO_3$ and KCl extracts interfered with molybdenum determination and the problem was not overcome by bromine oxidation as suggested for water samples (Lively, 1974). However, oxidation was accomplished by evaporating the extracts to dryness and muffling overnight at 550°C. The residue was dissolved in 1 ml concentrated hydrochloric acid. Alternatively, the $(NH_4)_2CO_3$ and KCl extracts were evaporated to near dryness and the organic matter oxidised with 15 ml nitric and 5 ml perchloric acids. Acid oxidation was unsatisfactory for the acid ammonium oxalate extracts because very large amounts of acid were required to react with oxalate.

In general, single rather than duplicate analyses were done during this study because of the large numbers of measurements required. However, Grimsby soil which had been treated with Ottawa sludge and incubated aerobically at 10°C for 84 days was used as a reference soil and standard errors for this soil indicate that the measurements of DTPA-extractable metals were highly reproducible (Table 3). Moreover, measurements for all six soils not treated with sludge but analysed at 42-day intervals during 25°C aerobic incubation, indicated that the measurements were highly reproducible. Similar data were obtained for the HOAc and $CaCl_2$-extractable metals. The pooled standard error calculated with duplicate measurements of extractable molybdenum for 18 soils ranging from 0.50 to 1.21 was ±0.052 μg Mo/g soil.

On completion of the studies it was recognized that although the soils had been ground with a porcelain mortar and pestle to minimize contamination prior to analysis, they had been passed through a brass 2 mm sieve. To determine whether the brass caused contamination, several soils were shaken in contact with the sieve for 0, 15, 45 and 90 seconds.

TABLE 3. MEANS AND STANDARD ERRORS OF DTPA-EXTRACTABLE METALS FROM THE SIX CONTROL SOILS AND FROM GRIMSBY SOIL TREATED WITH 2.5% OTTAWA SLUDGE

Soil	No. of Observations	Sludge	pH	Metals (µg/g soil)					
				Cd	Zn	Cu	Ni	Pb	Co
St. Thomas	4	No Sludge	5.09±0.01	0.07±0.005	5.47±0.16	1.78±0.07	0.23±0.01	2.23±0.09	<0.15
Vaudreuil	4	No Sludge	4.41±0.005	0.23±0.01	12.99±0.29	1.22±0.07	0.88±0.03	6.59±0.20	0.45±0.05
Grimsby	4	No Sludge	4.20±0.04	0.09±0.01	2.08±0.09	1.42±0.15	0.25±0.01	0.95±0.05	0.22±0.01
Haldimand	4	No Sludge	4.68±0.01	0.13±0.01	2.08±0.12	1.56±0.19	0.74±0.04	2.77±0.20	0.26±0.04
Rideau	4	No Sludge	5.15±0.02	<0.05	1.40±0.12	2.05±0.13	0.38±0.03	0.54±0.07	0.16±0.005
Wendover	4	No Sludge	5.03±0.02	0.23±0.01	8.17±0.16	1.96±0.08	1.49±0.09	5.01±0.15	0.56±0.03
Grimsby	7	Ottawa	-	0.25±0.01	7.99±0.12	10.99±0.16	0.39±0.01	5.15±0.13	0.17±0.01

The results (Table 4) indicated that sieving caused small increases in extractable Zn and Cu but did not affect the levels of other metals. In general, Zn contamination was less than Cu; however, both were appreciable when compared to the levels in soils which had been neither sieved nor treated with sludge. Sludge treatment usually contributed much more extractable Zn and Cu to soils than sieving. Information on the levels of Zn and Cu contributed by sludges may be obtained from Appendix, Tables A1 and A2.

TABLE 4. EFFECT ON DTPA-EXTRACTABLE Zn AND Cu OF PASSING SOILS THROUGH A BRASS SIEVE

Soil	Sludge Treatment	Sieving Time (sec)	Metal (µg/g soil)			
			Zn		Cu	
			Observed	Contamination	Observed	Contamination
St. Thomas	No Sludge	0	5.63		1.82	
		15	5.60	0	2.38	0.56
		45	5.63	0	2.16	0.34
		90	5.73	0.10	2.34	0.52
Rideau	No Sludge	0	0.86		0.69	
		15	1.19	0.33	1.25	0.56
		45	1.53	0.67	1.85	1.16
		90	2.05	1.19	2.47	1.78
Grimsby	Ottawa	0	8.2		11.4	
		15	9.8	1.6	15.0	3.6
		45	10.1	1.9	15.2	3.8
		90	9.0	0.8	13.0	1.6
Haldimand	Sarnia	0	32.8		5.2	
		15	35.0	2.2	7.8	2.6
		45	34.0	1.2	7.6	2.4
		90	33.5	0.7	6.8	1.6

3 RESULTS

3.1 Effects of Mixing Sludges and Soils

3.1.1 pH and extractable Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn

The complete data for soil pH and 0.005M DTPA, 0.5N HOAc, 0.05M EDTA and 0.01M $CaCl_2$-extractable metals from the soils (Table 2) treated with the sludges (Table 1) are presented in Appendix, Tables A1 to A6. Chromium and Sn were not detected in the DTPA extracts and no data are reported for them. Similarly, Cu, Ni, Pb, Co, Cr and Sn were not detected in the $CaCl_2$ extracts. A summary of pH and extractable Cd, Zn, Cu, Ni and Pb data which illustrates the effects of adding sludges to soils is presented in Tables 5, 6, 7 and 8 and is discussed below. Cobalt was barely detectable in the extracts (Appendix, Table A3) and the data were not included in the summary.

Measurements after incubation for 42 and 84 days indicated that the levels of extractable metals were approximately constant with time (Table 5). The variations were small and appeared to be random. The pH values for several of the Grimsby soil-sludge mixtures decreased approximately 0.5 units from 42 to 84 days; however, these were the largest changes observed for any of the soils and most showed no change at all (Appendix, Table A6). Overall means calculated with the data for all soils and six sludges, excluding Midland, are not shown, but exhibited remarkable agreement from 42 to 84 days for both the metal and pH measurements.

Adding sludge increased soil pH and this effect was most striking for the Newmarket, Midland and North Toronto sludges (Table 5) presumably because they contained the largest amounts of calcium carbonate. The Newmarket and Midland were lime treated sludges (Table 1) and the North Toronto had been limed prior to vacuum filtration. Adding sludge (except for Newmarket) enhanced the levels of DTPA-extractable metals in soil and the increases were related to the metal contents of the sludges (Table 6). For example, Ottawa sludge contained intermediate amounts of metals and caused intermediate increases in the levels of extractable metals in soil while Guelph sludge contained large amounts and caused large increases. Newmarket sludge contained small amounts

TABLE 5. pH AND DTPA-EXTRACTABLE METALS[1] (µg/g soil) FROM GRIMSBY SOIL TREATED WITH 2.5% SLUDGE AND INCUBATED MOIST AND AEROBIC AT 25°C FOR 42 AND 84 DAYS

Sludge	pH		Cd		Zn		Cu		Ni		Pb	
	Incubation Period (days)											
	42	84	42	84	42	84	42	84	42	84	42	84
No Sludge	4.2	4.1	0.06	0.12	2.0	1.9	1.0	1.4	0.25	0.23	0.96	0.80
Newmarket	7.6	7.6	0.07	0.09	2.0	1.7	2.1	2.2	0.19	0.18	1.0	0.94
Midland	7.1	NA	0.11	NA	6.2	NA	4.3	NA	4.8	NA	2.1	NA
Ottawa	6.1	5.8	0.26	0.22	6.8	6.9	10.6	10.5	0.29	0.38	4.9	4.5
North Toronto	7.1	6.5	0.48	0.58	13.5	13.4	11.2	9.5	0.17	0.23	6.8	6.0
Guelph	6.0	5.4	3.2	3.4	49	58	25	34	0.67	0.97	7.0	8.7
Sarnia	5.9	5.4	1.32	1.20	54	54	7.5	7.8	0.24	0.23	15.5	14.6
Fergus	6.2	5.7	0.48	0.44	84	82	63	66	1.11	1.15	2.6	2.5

[1] Cr and Sn were not detected in the extracts.

TABLE 6. TOTAL AND EXTRACTABLE METALS IN THE SLUDGES AND EXTRACTABLE METALS FROM GRIMSBY SOIL TREATED WITH 2.5% SLUDGE AND INCUBATED MOIST AND AEROBIC AT 25°C FOR 42 DAYS

Sludge	Cd	Zn	Cu	Ni	Pb
Total sludge metal added to soil (µg/g soil)					
Newmarket	0.04	14.3	4.6	0.3	0.2
Midland	0.01	33	9.4	54	12.9
Ottawa	0.33	45	29	2.6	20.9
North Toronto	0.83	65	36	0.7	49
Guelph	5.9	176	87	3.4	41
Sarnia	2.5	262	21.2	0.7	82
Fergus	0.58	239	153	5.5	8.8
DTPA-extractable sludge metal added to soil (µg/g soil)[1]					
Newmarket	<0.2	3.6	2.0	0.1	<1
Midland	<0.2	11.6	4.8	11.3	2.3
Ottawa	<0.2	13.7	5.6	0.9	7.1
North Toronto	0.75	33	14.8	0.2	10.5
Guelph	2.52	69	7.8	1.0	9.8
Sarnia	0.77	59	2.2	0.2	33
Fergus	0.34	146	26	3.2	3.8
DTPA-extractable metal from the sludge-soil mixtures (µg/g soil)					
No Sludge	0.06	2.0	1.0	0.2	1.0
Newmarket	0.07	2.0	2.1	0.2	1.0
Midland	0.11	6.2	4.3	4.8	2.1
Ottawa	0.26	6.8	10.6	0.3	4.9
North Toronto	0.48	13.5	11.2	0.2	6.8
Guelph	3.2	49	25	0.7	7.0
Sarnia	1.32	54	7.5	0.2	15.5
Fergus	0.48	84	63	1.1	2.6

[1] The amount of sludge contained in 20 g soil treated with 2.5% sludge (i.e., 0.5 g sludge) was extracted with 40 ml DTPA reagent.

TABLE 7. COMPARISON OF 0.005M DTPA, 0.5N HOAc, 0.05M EDTA AND 0.01M $CaCl_2$-EXTRACTABLE METALS (µg/g soil) FROM GRIMSBY SOIL TREATED WITH 2.5% SLUDGE AND INCUBATED MOIST AND AEROBIC AT 25°C FOR 42 DAYS

Sludge	Cd		Zn			Cu		Ni	
	DTPA	$CaCl_2$	DTPA	HOAc	$CaCl_2$	DTPA	EDTA	DTPA	HOAc
No Sludge	0.06	0.05	2.0	2.7	1.4	1.0	2.2	0.2	<2
Newmarket	0.07	<0.05	2.0	8.2	ND	2.1	5.7	0.2	<2
Midland	0.11	<0.05	6.2	19.4	ND	4.3	9.2	4.8	30
Ottawa	0.26	ND	6.8	14.6	0.2	10.6	18.7	0.3	<2
North Toronto	0.48	<0.05	13.5	38	<0.1	11.2	24	0.2	<2
Guelph	3.2	0.23	49	98	1.6	25	57	0.7	2.2
Sarnia	1.32	0.15	54	100	2.8	7.5	13.6	0.2	<2
Fergus	0.48	<0.05	84	134	2.1	63	107	1.1	2.7

ND = Not detected.

of metals and caused little change. In general, the increases in the levels of extractable metals in soils were about one-half as large as the amounts of extractable metals in sludge. The increases in Cu from the Ottawa, Guelph, Sarnia and Fergus sludges and in Cd from the Guelph, Sarnia and Fergus sludges were, however, larger than the amounts of extractable metals in these sludges.

TABLE 8. pH AND DTPA-EXTRACTABLE METALS FROM THE SOILS TREATED WITH GUELPH SLUDGE AND INCUBATED MOIST AND AEROBIC AT 25°C FOR 42 DAYS

Soil	pH	Cd	Zn	Cu	Ni	Pb
		Added in sludge (µg/g soil)				
		5.9	176	87	3.4	41
		DTPA-extractable (µg/g soil)				
St. Thomas	6.3	3.2	70	32	1.2	9.0
Vaudreuil	5.8	4.3	97	27	1.9	12.0
Grimsby	5.4	3.2	49	25	0.7	7.0
Haldimand	5.9	2.9	44	22	1.2	11.5
Rideau	6.4	2.7	40	22	0.8	9.3
Wendover	5.6	4.1	83	27	2.9	12.4

The 0.005M DTPA, 0.5N HOAc, 0.05M EDTA and 0.01M $CaCl_2$ reagents extracted different amounts of metals; however, the data exhibited similar trends (Table 7). DTPA generally extracted smaller amounts of Zn than HOAc and about one-half as much Cu as EDTA but these data for all of the sludge-soil mixtures had correlation coefficients, $r = 0.93$ and 0.99, respectively. HOAc-extractable Ni was not determined accurately for most mixtures because the method requires a small soil to HOAc ratio and only Midland sludge contained much Ni (Table 1). Similarly, Cd and Zn were detected in most of the $CaCl_2$ extracts but the amounts were not large enough to estimate accurately except in mixtures containing sludges with largest amounts of these metals.

The levels of some extractable metals in the sludge-soil mixtures appear to be related to soil properties (Table 8). For example,

DTPA-extractable Zn was larger from the mixtures of St. Thomas and Vaudreuil soils which contained small amounts of clay and of Vaudreuil and Wendover soils which contained large amounts of organic matter, than from the others. Similarly, DTPA-extractable Ni and Cd were larger from the mixtures of Vaudreuil and Wendover soils, but Cu and Pb exhibited no consistent relationships with either the organic matter or clay contents of the soils. HOAc-extractable Zn was larger from the mixtures with soils containing small amounts of clay but there appeared to be no consistent relationship with soil organic matter content (Appendix, Table A5). EDTA-extractable Cu from the mixtures appeared to be independent of soil properties (Appendix, Table A6) and $CaCl_2$-extractable Zn increased with increasing organic matter and decreasing clay contents of the soils (Appendix, Table A4). Too few $CaCl_2$-extractable Cd data were available for relationships with soil properties to be apparent (Appendix, Table A4). The levels of extractable metals did not appear to be closely related to the range of pH values (5.4 to 6.4) in these sludge-soil mixtures.

Analysis of variance for sludge-soil mixtures incubated moist and aerobic at 25°C confirmed that there were significant effects of sludge and soil properties on the levels of extractable metals. These effects are illustrated for DTPA-extractable Cd and Zn in Figure 1. Similar figures could have been presented for DTPA-extractable Cu, Ni and Pb, and HOAc-extractable Zn. Regression analysis indicated that the levels of extractable metals, except for Co, were related primarily to the amounts of metals in the sludges and secondarily to the soil properties (Table 9). For example, sludge Cd and Cu accounted for almost all of the differences in the levels of extractable Cd and Cu for the six soils considered individually and as a group. Hence, multiple regression analysis including soil properties exhibited little improvement over sludge metal alone. Sludge Zn, Ni and Pb accounted for large proportions of the differences in the levels of extractable Zn, Ni and Pb, respectively, for individual soils but smaller proportions for the soils as a group, indicating that soil properties exhibited appreciable effects on the extractabilities. DTPA-extractable Zn was related to percent clay and percent organic matter in the soils but showed little

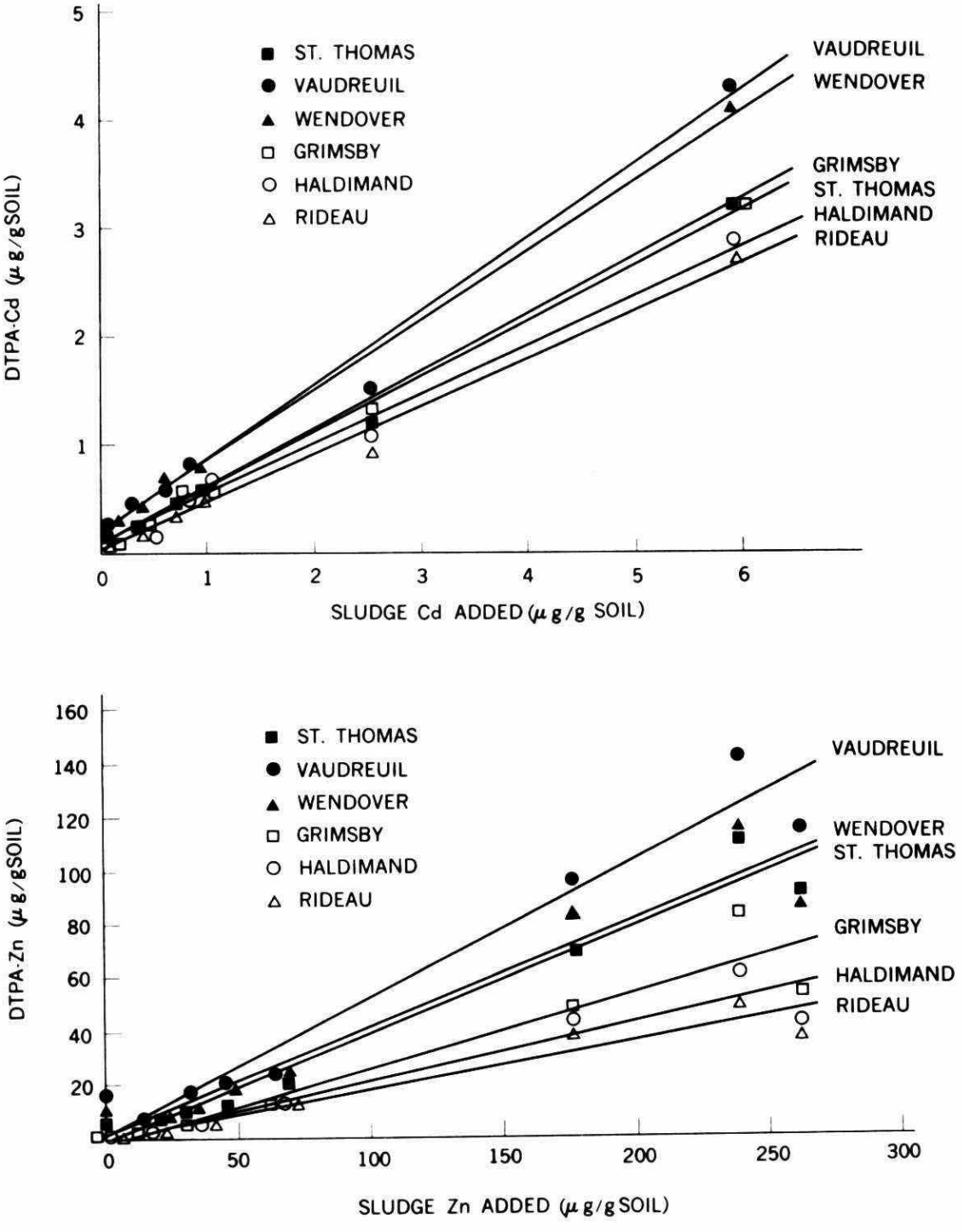

FIGURE 1. DTPA-EXTRACTABLE Cd AND Zn VERSUS TOTAL SLUDGE Cd AND Zn, RESPECTIVELY, ADDED TO SOILS

TABLE 9. RELATIONSHIPS BETWEEN EXTRACTABLE METALS AND SLUDGE AND SOIL PROPERTIES

Soils	% Reduction in Total Sums of Squares							
	DTPA -Cd	DTPA -Zn	HOAc -Zn	DTPA -Cu	EDTA -Cu	DTPA -Ni	DTPA -Pb	DTPA -Co
Linear Regression: Extractable metal on total sludge metal added to the soils								
St. Thomas	99.5	96.0	98.0	96.6	98.9	99.1	93.5	49.2
Vaudreuil	98.9	95.0	97.1	96.7	99.2	97.7	77.2	21.9
Grimsby	99.8	89.8	92.7	96.7	99.7	98.6	95.7	49.9
Haldimand	99.4	91.6	91.0	95.5	99.1	99.4	90.1	3.5
Rideau	99.3	93.0	93.5	97.9	99.7	99.6	90.8	5.8
Wendover	99.3	93.4	97.6	97.2	99.2	98.1	76.9	3.7
All Soils	94.6	74.5	81.6	94.0	98.8	79.7	79.4	0.8
Multiple Regression for all soils: Extractable metal on total sludge metal added to soils and								
Total Soil Metal		75.8	87.0	94.3	98.1		83.0	
pH		76.5					82.0	
CEC[1]		74.6	85.4			82.6	81.8	
% Clay		77.1	89.6	94.4	98.0			
% OM[2]	96.3	79.7		93.9	97.9	86.4	83.4	46.6
pH and % OM							84.7	50.1
% Clay and CEC						86.8		
% Clay and % OM	96.8	85.0				86.7		

[1] Cation exchange capacity.
[2] Organic matter.

relation to soil Zn, pH or cation exchange capacity. HOAc-extractable Zn was related to cation exchange capacity and soil Zn but was best related to percent clay. DTPA-extractable Ni and Pb were related to percent organic matter. DTPA-extractable Co generally exhibited little relationship with the small amounts of Co contained in the sludges but was related to the organic matter contents and possibly pH of the soils.

The extractable metal and soil property relationships were not improved by considering the amounts of sodium pyrophosphate-soluble carbon, iron, aluminum and manganese or ammonium oxalate-soluble iron, aluminum and manganese in the soils. Too few values for HOAc-extractable Ni and $CaCl_2$-extractable Cd and Zn were obtained to warrant doing regression analysis with the data. The detailed extractable metal and soil property relationships defined by linear and multiple regression analysis are presented in Appendix, Tables A7 to A10. The linear regression coefficients for "all soils" included in these Tables indicated that DTPA extracted an average of 55% of the Cd, 33% of the Zn, 39% of the Cu, 19% of the Ni and 17% of the Pb added to the soils in sludge. HOAc extracted an average of 40% of the Zn and EDTA extracted 71% of the Cu added to soils in sludge.

3.1.2 Extractable Mo

Detailed information concerning the quantities of Mo added to soil in the sludges and extracted from the sludge-soil mixtures after aerobic incubation for 42 and 84 days is contained in Appendix, Table A11. There were no consistent differences in extractable Mo related to incubation time; however, there were differences related to sludge treatment and extraction method and they are illustrated by the data for Grimsby soil in Table 10. Sludge treatment enhanced Mo extractability and the acid ammonium oxalate and $(NH_4)_2CO_3$ removed approximately equal and much larger amounts than KCl. The Newmarket, Ottawa and Guelph sludges added equal amounts of Mo to the soil; however, Mo extractability was greater from the Newmarket and Ottawa than the Guelph treatment. This result is probably related to the fact that the Newmarket and Ottawa sludges originally contained only 1 and 6 µg Mo/g sludge, respectively, (Table 1) and inorganic Mo was added to them prior to mixing

and incubation with soil. The Stratford sludge added a large amount of Mo and greatly enhanced extractability from the soil. The acid ammonium oxalate and $(NH_4)_2CO_3$ removed one-third to three-quarters, and KCl one-tenth to one-third of the Mo added to soil in sludge.

TABLE 10. EXTRACTABLE Mo (µg/g soil) FROM GRIMSBY SOIL TREATED WITH 2.5% SLUDGE AND INCUBATED MOIST AND AEROBIC AT 25°C FOR 42 DAYS

Sludge	Mo Added[1] (µg/g soil)	Extractant		
		Acid Ammonium[2] Oxalate	1N $(NH_4)_2CO_3$[3]	0.02N KCl
No sludge		0.15	0.04	0.01
Newmarket	1.9	1.22	1.48	0.75
Ottawa	1.9	2.02	1.56	0.40
Guelph	1.9	0.97	0.78	0.19
Stratford	28.2	18.0	19.0	8.8

[1] Sodium molybdate was added to the Newmarket and Ottawa sludges to give them the same content as Guelph sludge (i.e., 76 µg Mo/g sludge) prior to mixing with soil.
[2] Reisenauer (1965).
[3] Vlek and Lindsay (1977).

The Mo extracted with acid ammonium oxalate exhibited no consistent trends with soil properties. Measurements for the untreated Haldimand, Rideau and Wendover soils with high clay contents were larger than for the soils with low clay contents (Table 11). However, the reverse relationship was observed for the Stratford sludge treatment and no relationship was observed with the Newmarket, Ottawa and Guelph sludge treatments. The Vaudreuil and Wendover soils contained large amounts of organic matter and exhibited generally lower levels of acid ammonium oxalate-extractable Mo than the others but this relationship was not observed with the $(NH_4)_2CO_3$ and KCl data (Appendix, Table A11). Relationships between extractable Mo, Mo added to soils in sludge and soil properties were not statistically defined because the sludges added only 1.9 and 28.2 µg Mo/g soil.

TABLE 11. ACID AMMONIUM OXALATE-EXTRACTABLE Mo (µg/g soil) FROM THE SOILS TREATED WITH SLUDGE AND INCUBATED MOIST AND AEROBIC AT 25°C FOR 42 DAYS

Soil	Sludge Treatment				
	No Sludge	Newmarket	Ottawa	Guelph	Stratford
	Added in sludge				
	0	1.9	1.9	1.9	28.2
	Extracted				
St. Thomas	0.13	0.78	1.32	1.11	17.3
Vaudreuil	0.04	0.79	0.88	0.61	12.4
Grimsby	0.15	1.22	2.02	0.97	18.0
Haldimand	0.35	0.95	1.75	0.96	11.6
Rideau	0.36	1.10	1.10	1.32	11.7
Wendover	0.29	0.60	0.72	0.82	12.5

3.2 Effects of Varying Temperature, Aeration and pH

3.2.1 pH and extractable Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn

The complete data for soil pH and 0.005M DTPA-extractable metals from the Grimsby silt loam and Haldimand silty clay loam soils treated with the Ottawa and Sarnia sludges and incubated under a variety of simulated field conditions are presented in Appendix, Tables A12 and A13. Chromium and Sn were not detected in the extracts and no data are reported for them. A summary of data which illustrates the effects observed is presented in Tables 12, 13 and Figure 2 and is discussed below. Except for the effect of adding calcium carbonate, the simulated field conditions exhibited little effect on soil pH (Table 12). Calcium carbonate increased the pH of Grimsby soil by more than 3 units. Adding Sarnia sludge increased the pH by approximately 1.5 units and, with the exception of Ni, increased the levels of extractable metals. The levels of DTPA-extractable metals were much smaller and the effects of the various incubation conditions were smaller for the control than for the sludge treated soil. Assuming moist aerobic incubation at 25°C as the

TABLE 12. DTPA-EXTRACTABLE METALS[1] FROM GRIMSBY SILT LOAM SOIL TREATED WITH 2.5% SARNIA SLUDGE AND INCUBATED UNDER A VARIETY OF SIMULATED FIELD CONDITIONS FOR 84 DAYS

Treatment[2]		pH	Cd	Zn	Cu	Ni	Pb
			Added in sludge (µg/g soil)				
			2.5	262	21.2	0.7	82
			Extracted from soil (µg/g soil)				
-15°C	No Sludge	4.0	0.07	1.7	1.1	0.3	0.8
	Sludge	5.8	1.13	63	5.3	0.3	17.0
10°C	No Sludge	4.1	0.09	1.7	1.1	0.3	0.9
	Sludge	5.8	1.37	52	8.0	0.2	15.0
25°C	No Sludge	4.1	0.12	1.9	1.4	0.2	0.8
	Sludge	5.4	1.20	54	7.8	0.2	14.6
50°C	No Sludge	4.4	0.25	0.6	1.2	0.2	0.7
	Sludge	5.9	1.24	18.8	5.3	0.1	8.1
Alternate -15°C and 25°C	No Sludge	4.1	0.08	1.7	1.1	0.3	0.8
	Sludge	5.9	1.37	47	7.5	0.3	15.3
25°C, alternate aerobic and anaerobic	No Sludge	4.2	0.06	1.4	1.1	0.2	0.9
	Sludge	5.9	1.27	35	7.3	0.3	15.0
25°C anaerobic	No Sludge	4.2	0.07	1.7	1.1	0.2	1.0
	Sludge	6.1	0.74	28	3.3	0.2	16.4
25°C, $CaCO_3$ to pH 7	No Sludge	7.3	0.06	0.8	1.0	<0.1	0.7
	Sludge	7.4	1.26	23	9.5	<0.1	17.6
25°C, 10% $CaCO_3$	No Sludge	7.5	0.08	0.3	1.3	<0.1	0.7
	Sludge	7.3	1.35	25	8.7	<0.1	19.6

[1] Cr and Sn were not detected in the extracts.
[2] The treatments were maintained moist and aerobic, except as indicated.

reference, many treatments exhibited little effect on the levels of extractable metals. For example, extractable Cd in the control and sludge treated soils was largely independent of treatment except the 50°C and anaerobic incubations, respectively (Figure 2). Extractable Zn was reduced in the control soil by incubation at 50°C and in the sludge

treated soil by calcium carbonate addition, and the 50°C and anaerobic incubations. Furthermore, extractable Pb in the control soil was reduced by calcium carbonate addition and the 50°C incubation. Incubating the sludge treated soil at -15°C, 50°C and 25°C anaerobic reduced Cu; 50°C and calcium carbonate addition reduced Ni; and 50°C reduced Pb.

TABLE 13. MEANS OF DTPA-EXTRACTABLE METALS FROM GRIMSBY AND HALDIMAND SOILS TREATED WITH 2.5% SARNIA SLUDGE AND INCUBATED UNDER A VARIETY OF SIMULATED FIELD CONDITIONS FOR 84 DAYS

Treatment	pH	Metal Extracted From Soils (µg/g soil)				
		Cd	Zn	Cu	Ni	Pb
-15°C	5.87	1.03	58.5	5.60	0.45	18.5
10°C	5.92	1.31	49.9	7.80	0.43	18.2
25°C	5.65	1.22	49.5	8.10	0.38	17.2
50°C	6.27	1.39	15.1	4.95	0.16	12.0
Alternate -15°C and 25°C	5.99	1.30	44.2	7.55	0.43	16.4
25°C, alternate aerobic and anaerobic	6.10	1.17	26.9	6.05	0.32	11.9
25°C, anaerobic	6.40	0.70	25.9	3.30	0.24	10.6
25°C, $CaCO_3$ to pH 7	7.30	1.23	24.5	8.45	0.18	20.0
25°C, 10% $CaCO_3$	7.40	1.32	25.2	9.30	0.19	21.4
LSD (0.05)	0.45	0.25	9.2	1.79	0.18	NSD

NSD = No significant differences.
LSD = Least significant differences.

There were large differences in the levels of extractable metals between the no sludge and the Ottawa and Sarnia sludge treatments, and statistical calculations with overall means for the Grimsby and Haldimand soils and the three treatments would have been heavily biased

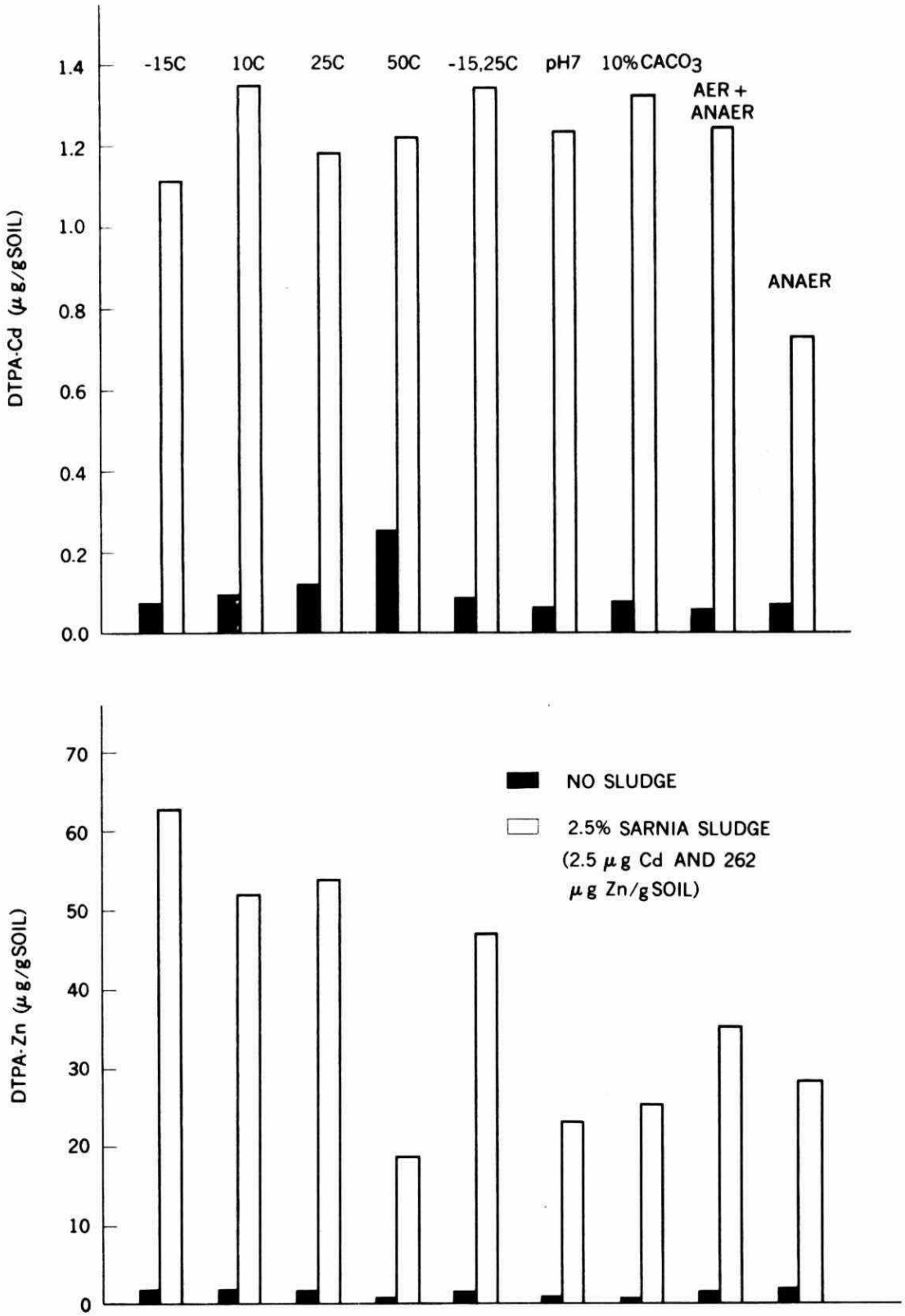

FIGURE 2. EFFECTS OF SIMULATED FIELD CONDITIONS ON THE EXTRACTABLE Cd AND Zn FROM CONTROL SOIL AND MIXTURES OF SARNIA SLUDGE AND GRIMSBY SOIL

by the Sarnia sludge treatment. Consequently, the calculations were done for each treatment individually using means for the two soils. Data for the Sarnia sludge are presented in Table 13 and similar results were obtained with the no sludge and Ottawa sludge treatments. The data are means of two single analyses and the least significant differences (LSD) were calculated assuming no sludge-soil interaction. Comparing the differences between means with the appropriate LSD indicates that incubating soils and sludge under a variety of simulated field conditions caused some significant differences in the levels of extractable metals. Many of the significant differences were those mentioned above for the data in Table 12. The LSD for Pb was very large because the levels of extractable Pb from Haldimand soil incubated under 25°C alternate aerobic and anaerobic, and 25°C anaerobic conditions were unusually small. Excluding the means for those two treatments would have given a smaller LSD and significant differences.

3.2.2 Extractable Mo

Sludge addition to the Grimsby and Haldimand soils increased the levels of acid ammonium oxalate-extractable Mo; however, incubation under a variety of simulated field conditions caused few consistent changes (Table 14). Assuming moist, aerobic incubation at 25°C as the reference treatment, there was no consistent effect on Mo extractability of increasing the temperature from -15°C to 25°C. Anaerobiosis reduced the values for Grimsby but not Haldimand soil and calcium carbonate addition exhibited no effect. Similar data obtained with other sludges and extracting reagents are presented in Appendix, Table A14.

3.3 Effects of Repeated Sludge Applications to Soils

3.3.1 pH and extractable Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn

The complete data for soil pH and 0.005M DTPA-extractable metals from the six soils (Table 2) treated with 2.5% increments of Midland, Guelph, Fergus and Sarnia sludges at 42-day intervals are presented in Appendix, Tables A15 to A19. Chromium and Sn were not

TABLE 14. ACID AMMONIUM OXALATE-EXTRACTABLE Mo (μg/g soil) FROM SOILS TREATED WITH 2.5% GUELPH SLUDGE AND INCUBATED UNDER A VARIETY OF SIMULATED FIELD CONDITIONS FOR 84 DAYS

Treatment[1]		Soil	
		Grimsby	Haldimand
-15°C	No Sludge	0.17	0.41
	Sludge	0.80	0.85
10°C	No Sludge	0.15	0.16
	Sludge	1.23	1.03
25°C	No Sludge	0.14	0.36
	Sludge	0.98	0.91
Alternate -15°C and 25°C	No Sludge	0.11	0.25
	Sludge	0.78	0.92
25°C alternate aerobic and anaerobic	No Sludge	0.13	0.32
	Sludge	0.67	0.82
25°C, anaerobic	No Sludge	0.14	0.41
	Sludge	0.56	1.14
25°C, 10% $CaCO_3$	No Sludge	0.10	0.29
	Sludge	0.96	1.00

[1] The treatments were maintained moist and aerobic, except as indicated.

detected in the extracts and no data are reported for them. All of the mixtures were incubated moist and aerobic at 25°C and the Sarnia sludge-soil mixtures were also incubated at 50°C. The data for Grimsby soil illustrate the results obtained and are presented in Table 15.

Repeated applications of the sludges to soil caused incremental increases in pH and the levels of DTPA-extractable metals. The Midland, Guelph, Fergus and Sarnia sludges contained large amounts of Ni; Cd, Zn, Cu and Pb; Zn and Cu; and Cd, Zn and Pb, respectively, and adding large amounts of them to soil caused very high levels of these metals to occur in the extracts. The levels of extractable Cd, Zn, Cu and Pb in the Sarnia sludge-soil mixtures incubated at 50°C were approximately one-half as large as at 25°C.

TABLE 15. pH AND DTPA-EXTRACTABLE METALS[1] FROM GRIMSBY SILT LOAM SOIL TREATED WITH 2.5% INCREMENTS OF THE MIDLAND, GUELPH, FERGUS AND SARNIA SLUDGES AT 42-DAY INTERVALS AND INCUBATED MOIST AND AEROBIC AT 25°C AND 50°C

Sludge Rate %	pH	Cd	Zn	Cu	Ni	Pb
		(µg/g soil)				
25°C						
No Sludge	4.2	0.09	2.1	1.4	0.25	0.95
Midland						
2.5	7.1	0.11	6.2	4.3	4.8	2.1
5.0	7.6	0.11	11.0	7.6	7.3	3.5
7.5	8.1	0.16	16.5	10.8	10.1	4.7
Guelph						
2.5	5.4	3.4	58	34	1.0	8.7
5.0	6.3	5.4	104	51	1.0	12.9
7.5	6.2	7.8	142	79	1.0	20.2
Fergus						
2.5	5.7	0.44	82	66	1.1	2.5
5.0	6.2	0.85	188	132	2.3	4.0
7.5	6.3	1.08	256	194	3.0	4.7
Sarnia						
2.5	5.4	1.2	54	7.8	0.24	15.1
5.0	6.1	2.5	93	14.9	0.21	31
7.5	6.6	3.1	125	20.6	0.33	45
50°C						
No Sludge	4.5	0.55	0.50	0.77	<0.20	0.78
Sarnia						
2.5	5.9	1.3	28	5.6	<0.20	10.2
5.0	6.4	1.7	36	7.6	<0.20	14.8
7.5	6.6	2.4	62	12.5	<0.20	24

[1] Cr and Sn were not detected in the extracts.

Selected extractable metals expressed as percentages of the total metals added to soils in sludge are presented in Table 16. The percentages were generally independent of sludge rate and were smaller

TABLE 16. SELECTED DTPA-EXTRACTABLE METALS AS PERCENTAGES OF THE TOTAL METALS ADDED TO SOILS IN SLUDGE

Incubation Temperature	Sludge Rate %	Soil					
		St. Thomas	Vaudreuil	Grimsby	Haldimand	Rideau	Wendover
Cd 25°C	Guelph						
	2.5	54	68	54	50	47	66
	5.0	44	64	45	55	49	65
	7.5	45	53	44	48	43	56
Zn 25°C	Sarnia						
	2.5	30	39	20	16	13	29
	5.0	27	29	17	16	12	22
	7.5	29	25	16	14	12	18
50°C	2.5	15	22	10	6	5	6
	5.0	13	22	7	6	4	6
	7.5	15	25	8	7	6	11
Cu 25°C	Fergus						
	2.5	48	45	41	41	32	42
	5.0	47	49	43	43	36	42
	7.5	49	39	42	42	37	35
Ni 25°C	Midland						
	2.5	23	27	8	16	12	27
	5.0	20	22	6	12	8	20
	7.5	19	21	6	10	9	17
Pb 25°C	Sarnia						
	2.5	18	11	17	22	22	13
	5.0	20	9	18	21	23	3
	7.5	20	8	18	19	20	2
50°C	2.5	11	20	11	18	18	13
	5.0	9	18	9	15	15	11
	7.5	10	11	9	15	17	7

after incubation at 50°C than at 25°C. The values for Cd and Cu were approximately the same for all soils but Zn, Ni and Pb showed differences which were probably related to soil properties. Overall average values for mixtures prepared with the four sludges and six soils at 25°C were 54, 21, 42, 16 and 16% for Cd, Zn, Cu, Ni and Pb, respectively. Similar results were observed for the 2.5% rates of seven sludges added to the soils (subsection 3.1.1) and the corresponding average percentages were 55, 33, 39, 19 and 17.

3.4 Effects of Sludge and Newspaper Applications to Soils

3.4.1 pH and extractable Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn

The DTPA-extractable metals from the soils treated with Guelph sludge and with Guelph sludge and newspaper and incubated moist and aerobic at 25°C for 84 days are presented in Table 17. In addition, the Cd and Zn data are presented in Figure 3.

TABLE 17. pH AND DTPA-EXTRACTABLE METALS (µg/g soil) FROM SOILS TREATED WITH 2.5% GUELPH SLUDGE AND 10% NEWSPAPER, AND INCUBATED MOIST AND AEROBIC AT 25°C FOR 84 DAYS

Soil	Treatment	pH	Cd	Zn	Cu	Ni	Pb
St. Thomas	Sludge	6.3	3.3	73	33	1.2	9.8
	Sludge & Newspaper	6.4	3.2	75	36	1.3	10.2
Vaudreuil	Sludge	5.8	4.2	101	30	2.0	12.1
	Sludge & Newspaper	6.0	3.9	96	36	2.1	12.5
Grimsby	Sludge	5.4	3.4	58	34	1.0	8.7
	Sludge & Newspaper	5.9	3.1	45	30	0.7	6.8
Haldimand	Sludge	5.9	3.3	51	32	1.3	12.6
	Sludge & Newspaper	6.2	3.3	45	33	1.0	11.5
Rideau	Sludge	6.4	2.9	39	27	0.8	9.4
	Sludge & Newspaper	6.5	2.8	35	26	0.7	9.2
Wendover	Sludge	5.6	4.2	83	30	2.9	11.9
	Sludge & Newspaper	6.1	4.0	73	34	2.5	13.4

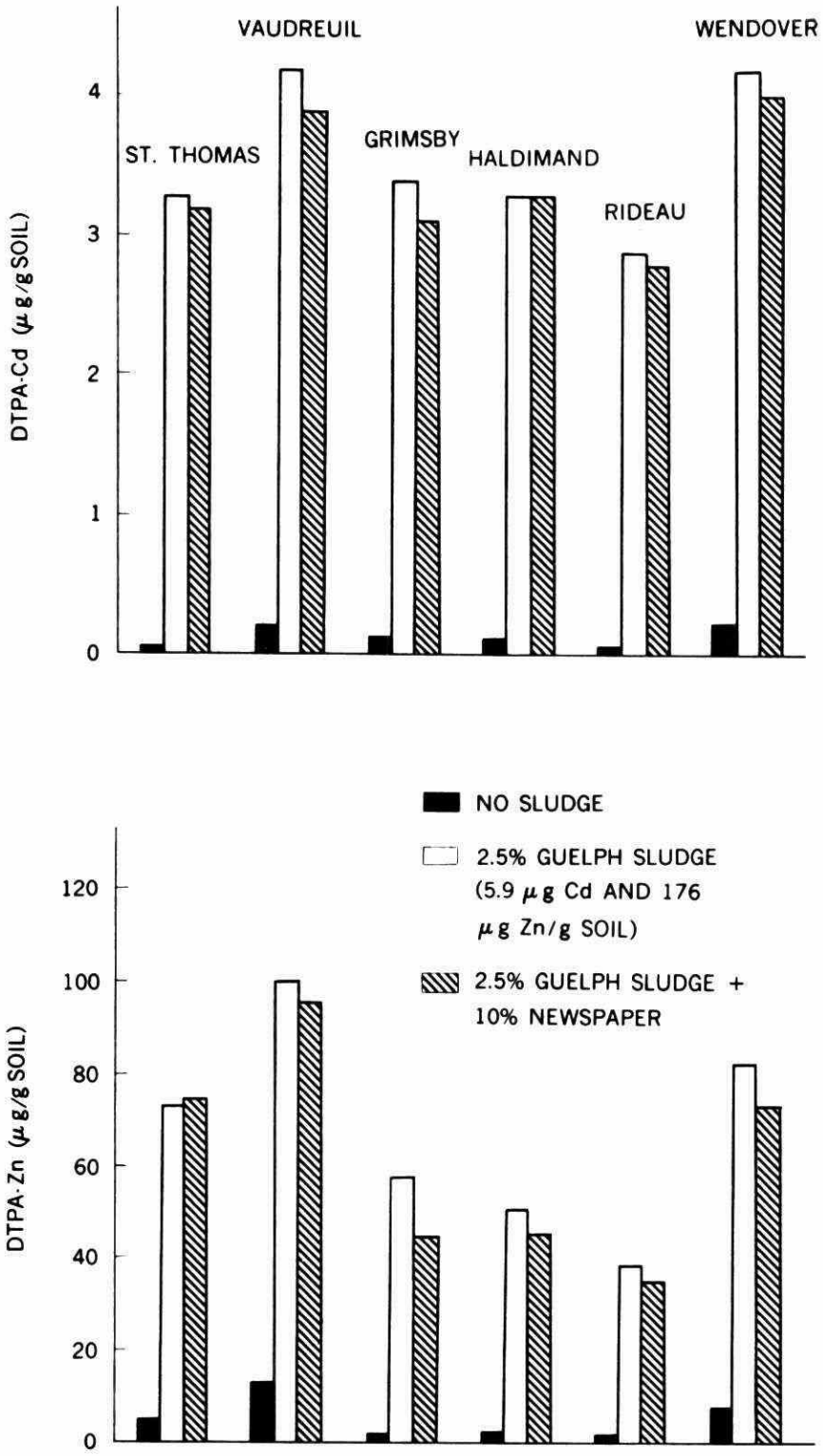

FIGURE 3. EFFECT OF NEWSPAPER ON THE EXTRACTABLE Cd AND Zn FROM CONTROL SOILS AND SLUDGE-SOIL MIXTURES

Incorporating sludge and shredded newspaper into the soils caused only minor differences in pH and extractable metals from the sludge treatment alone. In general, the newspaper treatment caused marginally higher pH and lower extractable Zn but exhibited no consistent effects on extractable Cd, Cu, Ni and Pb.

3.5 Leaching Sludge-Soil Columns

The complete data for Mo movement through columns of Grimsby, Haldimand and Wendover soils limed to pH 7, treated with Guelph and Stratford sludges and leached with 0.02M KCl are presented in Appendix, Tables A20 to A22. A summary of the data which illustrates the main effects observed is presented in Figure 4. All treatments were done in duplicate; however, data for the two replicates of no sludge and Guelph sludge treatments were similar and only one is shown. The data for both replicates of Stratford sludge treatment are shown. The Guelph and Stratford sludges added 62.7 and 931.4 µg Mo to the Grimsby and Wendover and 31.4 and 465.7 µg Mo to the Haldimand soil columns, respectively.

Leaching occurred more rapidly and much larger amounts of leachate were collected from the Grimsby and Wendover than from the Haldimand soil (Figure 4). Leaching occurred very slowly through the Haldimand soil even though it was mixed 1:1 (w/w) with <1 mm quartz to increase the permeability. Molybdenum was measured in the leachates of all soils; however, the quantities were small from the soils not treated with sludge, somewhat larger from the Guelph sludge treatments and very much larger from the Stratford sludge treatments. Loss of Mo from the Guelph sludge treatments occurred gradually, but from the Stratford sludge treatments was rapid initially and then, at least for Wendover soils, occurred more slowly. It appears that the experiments with Grimsby and Haldimand soils treated with Stratford sludge were terminated during the rapid initial phase. There was poor agreement particularly for the replicates of Wendover soil treated with Stratford sludge; however, leaching removed roughly 90, 45 and 20%, respectively, of the Mo added in Stratford sludge to Grimsby, Haldimand and Wendover soils. Similar values for the Guelph sludge treatment are 35, 12 and 15%, respectively.

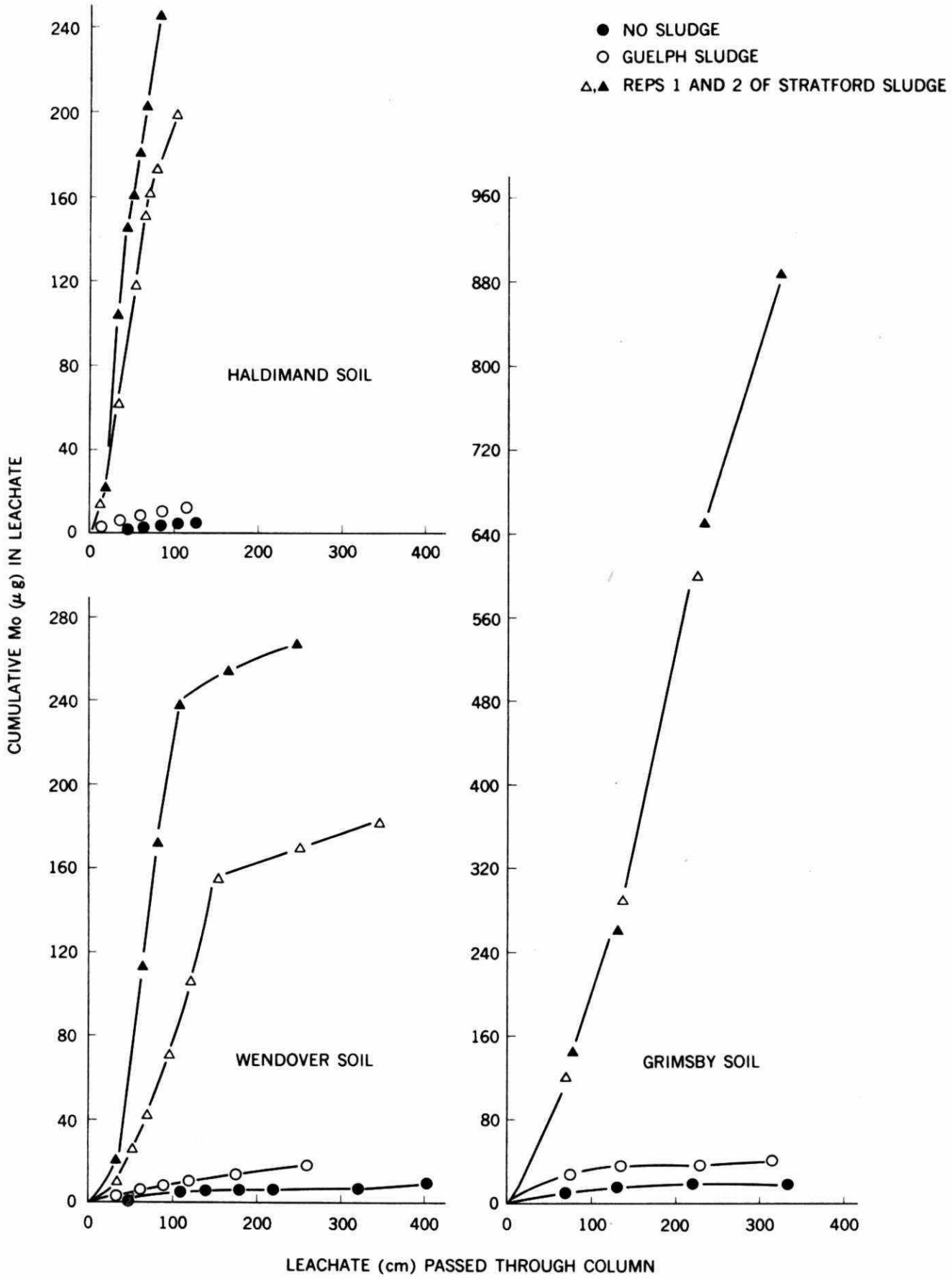

FIGURE 4. Mo MOVEMENT THROUGH COLUMNS OF SOIL TREATED WITH SLUDGES AND LEACHED WITH 0.02M KCL (68.73 CM = 1.0 LITRE)

4 DISCUSSION

Ontario soils exhibit wide ranges of chemical and physical properties and are subject to large variations in moisture content, temperature and oxygen tension. They are frozen during the winter, freeze and thaw during the spring and fall and are heated to temperatures in excess of 25°C during the summer. Normally they undergo alternate wetting and drying and remain aerobic, but excessive rainfall may cause short periods of waterlogging and anaerobiosis particularly if drainage is restricted. In this study, the laboratory incubation experiments included soils with a range of properties (Table 2) and were designed to simulate field conditions. For example, the -15°C treatment froze the soils and freezing and thawing occurred during the alternate -15°C and 25°C treatment. Incubation at 10°C approximated unfrozen spring and fall conditions and at 25°C, summer conditions. Probably 50°C never occurs in field soils in Ontario; however, it was introduced to increase the rate of sludge organic matter degradation and simulate extended incubation. It is the authors' opinion that incubation at 25°C for 42 days simulated one summer season because field soils are heated to approximately 25°C only during July and August, and it may have simulated one field year since much of the biological and chemical activity in Ontario soils occurs during those two months.

Several rates have been suggested for sludge application to agricultural soils in Ontario including sufficient sludge suspension to supply 120 lb of ammonium nitrogen per acre per year (OMAF, 1976). Ammonium nitrogen is readily plant available and 120 lb per acre is sufficient to produce optimum yields of most crops. Assuming that sludge suspensions contain an average of 4% solids the above rates correspond to (a) 2, (b) 4.5 and (c) 4 tons of sludge solids per acre per year. The 2.5% rate of sludge solids added to soils for the incubation studies was equivalent to 25 tons per acre or 56 metric tonnes per hectare. This rate is five to 10 times larger than recommended for agricultural use but was considered realistic for this study since a main objective was to consider metal solubilities in soils subjected to heavy loading with sludges.

The sludges employed in this study included two lime, four ferric chloride and two without P-removal chemical and were a small sample of those currently available for agricultural use in Ontario. Their total metal contents exhibited wide ranges from low to very high and were typical of data reported for other sludges from Ontario, Britain, Sweden and the United States (Gaynor and Webber, 1974; Page, 1974). The sludges with high metal contents had probably received large amounts of industrial contamination (Berrow and Webber, 1972; Abbott, 1971) and were chosen to study metal build-up in soils under extreme conditions. The soils exhibited wide ranges of exchange capacity and clay and organic matter contents; their total metal contents approximated the typical levels reported by Berrow and Webber (1972) and were generally much lower than for the sludges. The DTPA-extractable metals in the sludges were significantly correlated ($r = 0.87$) with their total metal contents and were greater than the levels of DTPA-extractable metals in the soils. This finding is consistent with a report by Berrow and Webber (1972) that sludges exhibited higher levels of HOAc-extractable metals than soils.

Increased levels of extractable Cd, Zn, Cu, Ni, Pb and Mo resulting from sludge application to soils concurred with previous reports (Boswell, 1975; Page, 1974; Webber, 1974; Webber and Hilliard, 1974; Webber and Gaynor, 1974); they were related primarily to sludge metal contents and secondarily if at all to soil properties. Low levels of extractable Co and no detectable Sn in treated soils probably reflected the low levels of these metals in the sludges (Table 1); however, no detectable Cr reflected very low solubility of this metal in the soils because several sludges contained large amounts of Cr. There appeared to be no relationship between extractable soil metals and the P-removal chemicals in the sludges; however, the number of sludges was too small to allow this observation to be tested statistically.

The levels of most of the extractable metals in the sludge-soil mixtures bore little, if any, relation to soil properties. The only appreciable relationships occurred between DTPA-extractable Zn and a combination of the clay and organic matter content of soils, HOAc-extractable Zn and clay content, and DTPA-extractable Ni and Pb and

organic matter content. The general absence of relationships between extractable metals and soil properties was unexpected since Cd, Zn, Cu, Ni and Pb are all sorbed by clay minerals and organic matter, and their solubilities decrease with increasing pH (Leeper, 1972; Ellis and Knezek, 1972; Lagerwerff, 1967). It is possible that increasing the degree of sludge degradation in the soils through further incubation might have improved the relationships; however, there were no differences between incubation for 42 and 84 days.

Increased levels of KCl-extractable Mo from mixtures prepared with soils limed to pH 7 and sludges containing as little as 76 µg Mo/g indicated a potential for Mo movement in soil and leaching experiments confirmed that it would occur. Molybdenum losses by leaching occurred most rapidly from soil with low clay and organic matter contents, but appreciable losses from three soils which exhibited wide ranges of clay and organic matter contents indicated that Mo build-up is not likely to be a serious problem in moderately to well drained, neutral to calcareous soils. These findings were consistent with reports that Mo toxicity in ruminants is usually caused by forage grown on poorly drained soils (Cheng and Ouellette, 1973). Increased levels of $CaCl_2$-extractable Cd and Zn from mixtures prepared with sludges containing large amounts of these metals also indicated a potential for leaching; however, no Cd was detected in the leachates of soils treated with Guelph sludge which exhibited a high Cd content.

Metal extractability from the sludge-soil mixtures was independent of the -15°C to 25°C range of temperatures normally occurring in Ontario soils and it was not appreciably affected by the addition of newspaper or, except for Zn, lime. Newspaper exhibits a very large C/N ratio and sludge nitrogen would have been required for its decomposition but this apparently did not affect metal extractabilities. Thus, mixing or composting domestic garbage with sewage sludge prior to land application is unlikely to reduce the plant availabilities of sludge metals. Mortvedt and Giordano (1975) have reported that the 0.5N HCl-extractable Zn and Cr in soils increased with increasing additions of these metals in garbage compost. Liming reduced Zn extractability in agreement with reports by MacLean (1974) and John (1972). Reductions of Zn and Pb at

50°C may have been due to increased sludge degradation and might imply long term reductions in the solubilities of these metals following field application of sludge. Furthermore, reductions of Cd, Zn and Cu during anaerobiosis may have resulted from sulphide formation (Engler and Patrick, 1975) because alternate anaerobiosis and aerobiosis caused no reduction of Cd and Cu and much less reduction of Zn. Neither 50°C nor long term anaerobiosis is likely to occur in Ontario soils recommended for sludge application.

The normal and toxic ranges of extractable Zn, Cu and Ni established for advisory work in Great Britain (Webber, 1974) are shown below:

Extractable Metal	Extractant	Normal (µg/g soil)	Toxic (µg/g soil)
Zn	0.5N HOAc	1-50	100-200
Cu	0.05M EDTA	0.5-5	50-100
Ni	0.5N HOAc	1-5	15-25

Calculations with data from the present study indicated that DTPA- and HOAc-extractable Zn (Appendix, Tables A1 and A4), DTPA- and EDTA-extractable Cu (Appendix, Tables A1 and A6) and DTPA- and HOAc-extractable Ni (data from Appendix, Tables A2 and A5 for mixtures prepared with the Midland, Guelph and Sarnia sludges) were highly correlated ($r = 0.93$, 0.99 and 0.86, respectively). The levels of DTPA-extractable metals corresponding to those reported by Webber (1974) were calculated from linear regression equations and are shown below:

DTPA-Extractable Metal	Normal (µg/g soil)	Toxic (µg/g soil)
Zn	0-38	75-158
Cu	0.5-3	28-56
Ni	0-2.5	6-10

Comparing the calculated values with data in Appendix, Tables A1, A2 and A5 indicated that a single 2.5% (56 tonnes/ha) application of the Guelph, Sarnia and Fergus sludges produced potentially toxic levels of Zn in three of the soils. Similarly, the Guelph and Fergus sludges produced potentially toxic levels of Cu, and Midland sludge produced potentially toxic levels of Ni in all six soils. Repeated applications of these sludges produced very high levels of many metals (Appendix, Tables A15 to A19).

DTPA-extractable Zn in the mixtures was related to the clay and organic matter contents of soils whereas Ni was related only to the organic matter contents. The amounts of total sludge metals required to produce 80 and 6 µg/g soil of DTPA-extractable Zn and Ni, respectively, calculated from regression equations for hypothetical soils with ranges of clay and organic matter are shown below:

Soil Properties		
Clay (%)	Organic Matter (%)	Total Sludge Metal (µg/g soil)[1]
		Zn
5	1	247
5	3	234
5	15	160
35	1	288
35	3	276
35	15	202
		Ni
	1	33
	3	31
	15	20

[1] 2 µg/g soil approximates 1 lb/0.5 acre foot (6" depth).

Metal guidelines for sludge use in agriculture have been adopted in England (Chumbley, 1971) and proposed for the United States (Chaney, 1973). The English guidelines assume that crop toxicities arise from Zn, Cu and Ni and that the toxicities are additive with Ni eight times and Cu twice as toxic as Zn. A "zinc equivalent" value is calculated for sludge according to (Zn + 2Cu + 8Ni) and not more than 250 mg/kg zinc equivalent of these metals will be added to soils with pH $\geq$6.5 during 30 to 50 years. Calculations shown below for the sludges used in this study indicated that the 2.5% rate of all but the Newmarket, Ottawa and North Toronto sludges added more than 250 mg/kg zinc equivalent of metals to the soils.

Sludge	Metal (mg/kg soil)[1]			Zinc Equivalents (mg/kg soil)
	Zn	Cu	Ni	
Newmarket	14.3	4.6	0.33	26
Midland	32.6	9.4	54	483
Ottawa	45.2	29.2	2.58	124
North Toronto	65	35.5	0.70	142
Guelph	176	87	3.35	377
Sarnia	262	21.2	0.73	310
Fergus	239	153	5.48	589
Stratford	54	32	24	310

[1] 2 mg/kg soil approximates 1 lb/0.5 acre foot (6" depth).

Chaney (1973) agreed that Zn, Cu and Ni pose the main threat for toxicity to crops but argued that the zinc equivalents concept overlooks Cd toxicity to animals. Evidence is increasing that Cd is readily taken up by plants and that forage which shows no toxicity symptoms itself may be toxic to animals. Moreover, there is evidence that metal binding is probably related to the soil cation exchange capacity and that this factor should be considered in guidelines. He argued that sludges with very large metal contents should not be spread

on land and defined agriculturally acceptable sludge as having less than 2000 ppm Zn, 800 ppm Cu, 100 ppm Ni, 100 ppm B, 1000 ppm Pb, 15 ppm Hg (dry solids basis), and a Cd/Zn ratio not exceeding 0.5%. Chaney (1973) recommended that metal additions to soils with pH ≥6.5 should not exceed zinc equivalent levels equal to 5% of their cation exchange capacities. Apparently plants do not differentiate between Cd and Zn during uptake and maintaining a 0.005:1 ratio would protect the food chain because Zn toxicity would reduce crop growth before the Cd content would constitute a health hazard. Assuming the above criteria, all of the sludges used in this study except Newmarket would be classed as unacceptable for use on agricultural land because of high metal contents (Table 1). However, the Cd to Zn ratios in the sludges and the zinc equivalents supplied in the 2.5% rate of sludge added to soil calculated as a percentage of soil cation exchange capacity are shown below:

Sludge	Cd/Zn Ratio	Soil					
		St. Thomas	Vaud-reuil	Grimsby	Hald-imand	Rideau	Wend-over
		Zinc Equivalent:Soil CEC (%)					
Newmarket	0.003	0.73	0.43	0.77	0.36	0.36	0.23
Midland	0.0002	13.5	8.0	14.2	6.7	6.7	4.3
Ottawa	0.007	3.5	2.1	3.7	1.7	1.7	1.1
North Toronto	0.013	4.0	2.4	4.2	2.0	1.9	1.2
Guelph	0.034	10.6	6.3	11.1	5.2	5.2	3.3
Sarnia	0.009	11.5	6.8	12.1	5.7	5.7	3.6
Fergus	0.002	16.5	9.8	17.3	8.2	8.1	5.2
Stratford	0.029	10.9	6.6	11.5	5.4	5.4	3.4

The Cd/Zn ratios of the Ottawa, North Toronto, Guelph, Sarnia and Stratford sludges exceeded 0.005 and the zinc equivalents frequently exceeded 5% of the soil cation exchange capacities. Cation exchange capacities of soils increase with increasing organic matter and clay

contents and the values of zinc equivalent:soil CEC were lowest for the Wendover soil which contained large amounts of both of these constituents.

Thus, the foregoing indicates that land application of Ontario sewage sludges will increase the soluble quantities of Cd, Zn, Cu, Ni, Pb and Mo in soils and uncontrolled application of sludges containing large amounts of these metals will cause excessive increases. High metal solubilities in soils are likely to cause crop and animal toxicities; however, further work is required to define the critical levels for Ontario conditions. Molybdenum leached slowly from soils adjusted to pH 7 and high levels of that metal are not expected to persist in agricultural soils.

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APPENDIX

Detailed Results of Incubation and Leaching Experiments

TABLE A1. 0.005M DTPA-EXTRACTABLE Zn AND Cu (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED AT 25°C FOR 42 AND 84 DAYS

Sludge	Sludge Metal Added (µg/g soil)		Soil											
			St. Thomas		Vaudreuil		Grimsby		Haldimand		Rideau		Wendover	
	Total	DTPA-Extractable	Incubation Period (days)											
			42	84	42	84	42	84	42	84	42	84	42	84
Zn														
No Sludge	0	0	5.5	5.0	13.3	12.3	2.0	1.9	1.8	2.0	1.4	1.6	8.1	7.9
Newmarket	14.3	3.6	4.9	4.7	7.8	6.8	2.0	1.7	1.7	1.7	2.6	1.7	4.1	3.5
Midland	33	11.6	11.6	-	15.5	-	6.2	-	5.8	-	5.6	-	11.3	-
Ottawa	45	13.7	12.5	11.2	19.8	17.7	6.8	6.9	6.0	6.1	6.1	5.4	17.6	16.4
North Toronto	65	33	22.4	19.0	24.8	22.4	13.5	13.4	13.8	11.4	13.6	10.4	24.4	22.5
Guelph	176	69	70	73	97	101	49	58	44	51	40	39	83	83
Sarnia	262	59	92	74	116	114	54	54	43	45	39	34	87	83
Fergus	239	146	112	105	143	147	84	82	61	65	51	47	115	111
Cu														
No Sludge	0	0	1.8	1.6	1.1	1.1	1.0	1.4	1.0	1.5	2.1	1.9	1.4	2.4
Newmarket	4.6	2	2.2	2.2	2.0	2.0	2.1	2.2	2.0	1.9	2.3	1.6	1.8	2.3
Midland	9.4	4.8	6.1	-	4.4	-	4.3	-	5.8	-	4.5	-	4.5	-
Ottawa	29	5.6	11.6	11.9	11.8	10.8	10.6	10.5	10.7	11.7	9.2	9.5	12.0	10.8
North Toronto	36	14.8	12.1	10.7	10.8	9.6	11.2	9.5	10.8	10.5	8.9	8.3	10.4	10.8
Guelph	87	7.8	32	33	27	30	25	34	22.2	32	22.1	27	27	30
Sarnia	21.2	2.2	11.0	8.7	6.8	7.6	7.5	7.8	6.4	8.4	5.3	6.6	7.0	7.6
Fergus	153	26	79	71	68	72	63	66	60	69	49	53	65	66

TABLE A2. 0.005M DTPA-EXTRACTABLE Ni AND Pb (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED AT 25°C FOR 42 AND 84 DAYS

Sludge	Sludge Metal Added (µg/g soil)		Soil											
			St. Thomas		Vaudreuil		Grimsby		Haldimand		Rideau		Wendover	
	Total	DTPA-Extractable	Incubation Period (days)											
			42	84	42	84	42	84	42	84	42	84	42	84
Ni														
No Sludge	0	0	0.22	0.21	0.86	0.83	0.25	0.23	0.64	0.70	0.32	0.35	1.38	1.30
Newmarket	0.33	0.1	0.22	0.24	0.53	0.54	0.19	0.18	0.42	0.43	0.23	0.30	0.82	0.87
Midland	54	11.3	12.7	-	15.4	-	4.8	-	9.3	-	6.8	-	15.9	-
Ottawa	2.6	0.91	0.77	0.73	1.54	1.47	0.29	0.38	0.84	0.72	0.58	0.47	2.3	2.1
North Toronto	0.70	0.24	0.28	0.33	0.68	0.72	0.17	0.23	0.48	0.44	0.29	0.30	1.38	1.33
Guelph	3.4	0.95	1.21	1.22	1.87	1.95	0.67	0.97	1.21	1.28	0.79	0.80	2.9	2.9
Sarnia	0.73	0.15	0.29	0.33	0.78	0.87	0.24	0.23	0.24	0.52	0.28	0.22	1.44	1.41
Fergus	5.5	3.24	2.6	2.4	4.3	4.3	1.11	1.15	1.82	1.67	1.26	1.13	4.5	4.5
Pb														
No Sludge	0	0	2.0	1.4	6.6	6.2	0.96	0.80	2.6	2.3	0.45	0.40	5.2	4.5
Newmarket	2.3	<1	1.5	1.0	3.3	2.7	1.0	0.94	1.8	1.7	0.96	0.80	3.1	2.6
Midland	12.9	2.3	4.7	-	5.7	-	2.1	-	4.1	-	2.2	-	5.6	-
Ottawa	20.9	7.1	7.1	7.0	9.7	9.0	4.9	4.5	8.2	7.9	5.7	5.1	10.6	9.6
North Toronto	49	10.5	7.8	6.5	8.9	7.7	6.8	6.0	8.0	6.7	6.2	5.2	9.0	8.4
Guelph	41	9.8	9.0	9.8	12.0	12.1	7.0	8.7	11.5	12.6	9.3	9.4	12.4	11.9
Sarnia	82	33	17.6	15.9	14.0	16.5	15.5	14.6	21.5	19.8	19.5	17.1	14.4	16.5
Fergus	8.8	3.8	3.6	3.6	6.0	5.8	2.6	2.5	4.3	4.8	2.7	2.7	6.3	5.6

TABLE A3. 0.005M DTPA-EXTRACTABLE Co AND Cd (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED AT 25°C FOR 42 AND 84 DAYS

Sludge	Sludge Metal Added (µg/g soil)		Soil											
			St. Thomas		Vaudreuil		Grimsby		Haldimand		Rideau		Wendover	
	Total	DTPA-Extractable	Incubation Period (days)											
			42	84	42	84	42	84	42	84	42	84	42	84
Co														
No Sludge	0	0	<0.15	<0.15	0.54	0.52	0.24	0.25	0.21	0.19	<0.15	0.15	0.56	0.50
Newmarket	0	<0.2	<0.15	0.16	0.25	0.19	0.23	0.18	0.32	0.21	0.23	0.15	0.29	0.30
Midland	0.29	<0.2	0.30	-	0.30	-	<0.15	-	0.29	-	0.26	-	0.35	-
Ottawa	0.31	<0.2	0.27	0.18	0.27	0.36	<0.15	0.21	0.29	0.21	0.25	<0.15	0.32	0.24
North Toronto	0.29	<0.2	0.20	<0.15	0.25	0.21	<0.15	0.22	0.32	0.24	<0.15	0.19	0.25	0.33
Guelph	0.25	<0.2	<0.15	<0.15	0.18	<0.15	0.21	0.37	0.19	0.18	<0.15	<0.15	0.74	0.98
Sarnia	0.17	<0.2	0.19	<0.15	0.51	0.43	0.25	0.27	0.34	0.22	0.18	<0.15	0.51	0.33
Fergus	0.13	<0.2	<0.15	<0.15	0.65	0.70	0.16	0.25	<0.15	<0.15	<0.15	<0.15	0.77	1.33
Cd														
No Sludge	0	0	0.06	0.05	0.23	0.20	0.06	0.12	0.10	0.11	<0.05	<0.05	0.20	0.21
Newmarket	0.04	<0.2	0.11	0.09	0.22	0.18	0.07	0.09	0.10	0.11	0.08	0.06	0.17	0.20
Midland	0.01	<0.2	0.08	-	0.22	-	0.11	-	0.13	-	0.06	-	0.23	-
Ottawa	0.33	<0.2	0.24	0.22	0.41	0.37	0.26	0.22	0.26	0.24	0.18	0.16	0.40	0.36
North Toronto	0.83	0.75	0.49	0.52	0.73	0.73	0.48	0.58	0.56	0.56	0.41	0.37	0.72	0.72
Guelph	5.9	2.52	3.2	3.3	4.3	4.2	3.2	3.4	2.9	3.3	2.7	2.9	4.1	4.2
Sarnia	2.5	0.77	1.19	1.12	1.50	1.55	1.32	1.20	1.10	1.24	0.95	1.00	1.55	1.64
Fergus	0.58	0.34	0.45	0.45	0.62	0.65	0.48	0.44	0.45	0.51	0.34	0.39	0.67	0.70

TABLE A4. 0.01M $CaCl_2$-EXTRACTABLE Zn AND Cd (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED AT 25°C FOR 42 AND 84 DAYS

Sludge	Sludge Metal Added (µg/g soil)		Soil											
			St. Thomas		Vaudreuil		Grimsby		Haldimand		Rideau		Wendover	
	Total	DTPA-Extractable	Incubation Period (days)											
			42	84	42	84	42	84	42	84	42	84	42	84
Zn														
No Sludge	0	0	0.40	0.41	1.54	1.68	1.44	1.20	0.16	0.15	<0.10	<0.10	0.13	0.20
Newmarket	14.3	3.6	ND	ND	ND	ND	ND	<0.10	ND	ND	<0.10	ND	ND	<0.10
Midland	33	11.6	<0.10	-	ND	-	ND	-	ND	-	ND	-	ND	-
Ottawa	45	13.7	0.12	<0.10	0.30	0.20	0.17	0.20	<0.10	<0.10	<0.10	ND	0.22	0.16
North Toronto	65	33	<0.10	<0.10	<0.10	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	0.17
Guelph	176	69	1.04	1.25	2.9	3.4	1.55	7.3	0.20	0.74	<0.10	0.12	1.72	1.67
Sarnia	262	59	1.53	1.84	6.0	5.7	2.8	9.5	0.42	0.99	0.16	0.29	1.72	1.75
Fergus	239	146	2.5	2.3	0.85	0.82	2.1	5.3	0.19	0.66	<0.10	0.17	3.1	3.2
Cu														
No Sludge	0	0	<0.05	<0.05	0.05	<0.05	0.05	0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Newmarket	0.04	<0.2	ND	<0.05	<0.05	<0.05	<0.05	<0.05	ND	<0.05	<0.05	<0.05	<0.05	<0.05
Midland	0.01	<0.2	0.05	-	ND	-	<0.05	-	ND	-	<0.05	-	<0.05	-
Ottawa	0.33	<0.2	ND	<0.05	ND	<0.05	ND	<0.05	ND	<0.05	ND	<0.05	ND	<0.05
North Toronto	0.83	0.75	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05
Guelph	5.9	2.52	0.07	0.10	0.11	0.12	0.23	0.60	<0.05	0.08	0.05	0.07	0.13	0.12
Sarnia	2.5	0.77	<0.05	<0.05	0.08	0.06	0.15	0.26	<0.05	<0.05	<0.05	<0.05	0.05	<0.05
Fergus	0.58	0.34	<0.05	<0.05	0.05	0.05	<0.05	0.08	<0.05	<0.05	ND	0.06	<0.05	<0.05

ND = Not detected.

TABLE A5. 0.5N HOAc-EXTRACTABLE Zn AND Ni (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED AT 25°C FOR 42 AND 84 DAYS

Sludge	Sludge Metal Added (µg/g soil)		Soil											
			St. Thomas		Vaudreuil		Grimsby		Haldimand		Rideau		Wendover	
	Total	DTPA-Extractable	Incubation Period (days)											
			42	84	42	84	42	84	42	84	42	84	42	84
Zn														
No Sludge	0	0	7.3	7.8	10.1	11.6	2.7	3.6	<2.0	2.5	<2.0	2.0	5.7	7.0
Newmarket	14.3	3.6	14.4	15.2	13.5	12.8	8.2	8.8	4.8	5.6	5.1	5.6	7.1	8.0
Midland	33	11.6	23.2	-	19.8	-	19.4	-	12.5	-	13.1	-	7.2	-
Ottawa	45	13.7	23.1	24.2	20.6	20.4	14.6	14.2	7.9	9.2	7.8	10.4	11.8	15.2
North Toronto	65	33	56	49	38	33	38	34	23.9	23.8	27	26	28	26
Guelph	176	69	107	102	99	95	98	96	55	59	57	54	66	68
Sarnia	262	59	139	123	120	117	100	88	58	58	61	54	86	77
Fergus	239	146	144	150	138	139	134	132	83	82	77	70	95	93
Ni														
No Sludge	0	0	<2.0	ND	<2.0	<2.0	<2.0	<2.0	<2.0	ND	<2.0	ND	<2.0	ND
Newmarket	0.33	0.1	<2.0	<2.0	2.1	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.3	<2.0
Midland	54	11.3	27	-	27	-	30	-	23	-	25	-	38	-
Ottawa	2.6	0.91	<2.0	<2.0	2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
North Toronto	0.70	0.24	<2.0	<2.0	<2.0	ND	<2.0	<2.0	<2.0	<2.0	<2.0	ND	2.3	<2.0
Guelph	3.4	0.95	2.3	2.3	2.8	2.9	2.2	2.2	2.4	2.3	2.3	2.0	2.8	2.7
Sarnia	0.73	0.15	<2.0	<2.0	<2.0	<2.0	<2.0	ND	<2.0	<2.0	<2.0	ND	<2.0	<2.0
Fergus	5.5	3.24	3.9	3.7	4.2	4.3	2.7	2.7	3.3	3.1	2.7	2.6	3.9	3.8

ND = Not detected.

TABLE A6. SOIL pH AND 0.05M EDTA-EXTRACTABLE Cu (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED AT 25°C FOR 42 AND 84 DAYS

Sludge	Sludge Metal Added (µg/g soil)		Soil											
			St. Thomas		Vaudreuil		Grimsby		Haldimand		Rideau		Wendover	
	Total	DTPA-Extractable	Incubation Period (days)											
			42	84	42	84	42	84	42	84	42	84	42	84
pH														
No Sludge			5.1	5.1	4.4	4.4	4.2	4.1	4.7	4.7	5.2	5.1	5.0	5.1
Newmarket			7.7	7.6	7.5	7.5	7.6	7.6	7.6	7.6	7.6	7.6	7.3	7.2
Midland			7.3	-	7.0	-	7.1	-	7.2	-	7.3	-	6.7	-
Ottawa			6.7	6.7	6.1	6.1	6.1	5.8	6.3	6.4	6.7	6.6	5.8	5.7
North Toronto			7.1	7.1	6.6	6.5	7.1	6.5	6.7	6.7	7.0	7.0	6.1	6.0
Guelph			6.3	6.3	5.8	5.8	6.0	5.4	6.2	5.9	6.5	6.4	5.6	5.6
Sarnia			6.4	6.3	5.6	5.7	5.9	5.4	6.2	5.9	6.4	6.3	5.7	5.6
Fergus			6.4	6.4	5.6	5.6	6.2	5.7	6.5	6.1	6.7	6.6	5.6	5.6
Cu														
No Sludge	0	0		3.0		2.6		2.2		2.2		2.6		4.2
Newmarket	4.6	2		6.0		6.2		5.7		5.5		5.1		7.3
Midland	9.4	4.8		8.3		10.2		9.2		9.1		7.9		11.1
Ottawa	29	5.6		23.9		24.3		18.7		22.7		20.6		24.4
North Toronto	36	14.8		27		26		23.6		27		25.5		26
Guelph	87	7.8		61		61		57		54		51		57
Sarnia	21.2	2.2		19.0		19.0		13.6		15.9		14.1		18.2
Fergus	153	26		130		124		107		111		95		114

TABLE A7. RELATIONSHIPS BETWEEN 0.005M DTPA- AND 0.5N HOAc-EXTRACTABLE Zn, AND SLUDGE AND SOIL PROPERTIES

Soil	Intercept	Coefficient	% Reduction in Total Sums of Squares
Linear regression: DTPA-extractable Zn on sludge Zn			
St. Thomas	-0.68±4.83	0.40±0.034	96.0
Vaudreuil	1.82±6.79	0.51±0.047	95.0
Grimsby	-1.92±5.50	0.28±0.038	89.8
Haldimand	-0.17±3.81	0.22±0.027	91.6
Rideau	0.78±2.93	0.18±0.021	93.0
Wendover	1.82±6.23	0.40±0.043	93.4
All Soils	0.28±4.10	0.33±0.029	74.5
Multiple regression for all soils: DTPA-extractable Zn on:			
Sludge Zn and pH			76.5
Sludge Zn and % clay			77.1
Sludge Zn and % organic matter			79.7
Sludge Zn, % clay and % organic matter			85.0
DTPA-Zn (µg/g soil) = -1.16±4.53+0.33±0.22 sludge Zn (µg/g soil)+2.04±0.42% organic matter-0.46±0.12% clay			
Linear regression: HOAc-extractable Zn on sludge Zn			
St. Thomas	8.10±4.46	0.54±0.031	98.0
Vaudreuil	5.93±4.96	0.49±0.035	97.1
Grimsby	3.14±7.65	0.47±0.053	92.7
Haldimand	0.36±5.21	0.28±0.036	91.0
Rideau	1.27±4.29	0.28±0.030	93.5
Wendover	1.21±3.27	0.36±0.023	97.6
All Soils	3.32±4.04	0.40±0.028	81.6
Multiple regression for all soils: HOAc-extractable Zn on:			
Sludge Zn and CEC			85.4
Sludge Zn and soil Zn			87.0
Sludge Zn and % clay			89.6
HOAc-Zn (µg/g soil) = 18.13±4.0+0.40±0.21 sludge Zn (µg/g soil)-0.64±0.11% clay			

TABLE A8. RELATIONSHIPS BETWEEN 0.005M DTPA- AND 0.05M EDTA-EXTRACTABLE Cu, AND SLUDGE AND SOIL PROPERTIES

Soil	Intercept	Coefficient	% Reduction in Total Sums of Squares
Linear regression: DTPA-extractable Cu on sludge Cu			
St. Thomas	-1.10±2.38	0.48±0.037	96.6
Vaudreuil	-1.36±2.05	0.42±0.032	96.7
Grimsby	-0.90±1.89	0.39±0.029	96.7
Haldimand	-0.53±2.09	0.36±0.032	95.5
Rideau	0.15±1.17	0.30±0.018	97.9
Wendover	-0.93±1.79	0.40±0.028	97.2
All Soils	-0.78±0.95	0.39±0.015	94.0
Multiple regression for all soils: DTPA-extractable Cu on sludge Cu and % clay			94.4
Linear regression: EDTA-extractable Cu on sludge Cu			
St. Thomas	0.47±2.26	0.81±0.035	98.9
Vaudreuil	1.43±1.79	0.77±0.028	99.2
Grimsby	0.83±1.02	0.68±0.016	99.7
Haldimand	1.56±1.77	0.69±0.027	99.1
Rideau	2.44±0.85	0.59±0.013	99.7
Wendover	3.13±1.61	0.70±0.025	99.2
All Soils	1.64±1.01	0.71±0.016	97.8
Multiple regression for all soils: EDTA-extractable Cu on sludge Cu and % clay			98.0

TABLE A9. RELATIONSHIPS BETWEEN 0.005M DTPA-EXTRACTABLE Ni AND Pb AND SLUDGE AND SOIL PROPERTIES

Soil	Intercept	Coefficient	% Reduction in Total Sums of Squares
Linear regression: DTPA-extractable Ni on sludge Ni			
St. Thomas	0.35±0.18	0.23±0.009	99.1
Vaudreuil	0.98±0.33	0.27±0.017	97.7
Grimsby	0.25±0.08	0.08±0.004	98.6
Haldimand	0.49±0.10	0.16±0.005	99.4
Rideau	0.30±0.06	0.12±0.003	99.6
Wendover	1.58±0.29	0.27±0.15	98.1
All Soils	0.66±0.27	0.19±0.014	79.7
Multiple regression for all soils: DTPA-extractable Ni on:			
Sludge Ni and CEC			82.6
Sludge Ni and % organic matter			86.4
Sludge Ni, % clay and % organic matter			86.8
DTPA-Ni (µg/g soil) = -0.41±0.32+0.19±0.01 sludge Ni (µg/g soil)+0.18±0.04% organic matter			
Linear regression: DTPA-extractable Pb on sludge Pb			
St. Thomas	1.85±0.72	0.18±0.019	93.5
Vaudreuil	5.28±0.93	0.11±0.025	77.2
Grimsby	0.57±0.55	0.17±0.015	95.7
Haldimand	1.88±1.11	0.22±0.029	90.1
Rideau	0.15±1.04	0.21±0.027	90.8
Wendover	5.02±1.03	0.12±0.027	76.9
All Soils	2.46±0.48	0.17±0.013	79.4
Multiple regression for all soils: DTPA-extractable Pb on:			
Sludge Pb and pH			82.0
Sludge Pb and % organic matter			83.4
Sludge Pb and soil Pb			83.0
Sludge Pb, pH and % organic matter			84.7
Sludge Pb, pH and soil Pb			85.0
DTPA-Pb (µg/g soil) = 1.35±0.55+0.17±0.01 sludge Pb (µg/g soil)+0.18±0.06% organic matter			

TABLE A10. RELATIONSHIPS BETWEEN 0.005M DTPA-EXTRACTABLE Co AND Cd AND SLUDGE AND SOIL PROPERTIES

Soil	Intercept	Coefficient	% Reduction in Total Sums of Squares
Linear regression: DTPA-extractable Co on sludge Co			
St. Thomas	0.14±0.029	0.33±0.136	49.2
Vaudreuil	0.48±0.105	-0.63±0.487	21.9
Grimsby	0.24±0.022	0.25±0.101	49.9
Haldimand	0.25±0.048	0.10±0.222	3.5
Rideau	0.17±0.033	0.09±0.152	5.8
Wendover	0.55±0.152	-0.34±0.706	3.7
All Soils	0.30±0.041	-0.11±0.190	0.8
Multiple regression for all soils: DTPA-extractable Co on:			
% organic matter			46.6
pH and % organic matter			50.1
Linear regression: DTPA-extractable Cd on sludge Cd			
St. Thomas	0.07±0.034	0.52±0.015	99.5
Vaudreuil	0.17±0.067	0.68±0.029	98.9
Grimsby	0.08±0.022	0.53±0.010	99.8
Haldimand	0.11±0.034	0.46±0.015	99.4
Rideau	0.04±0.034	0.44±0.015	99.3
Wendover	0.18±0.050	0.65±0.022	99.3
All Soils	0.11±0.044	0.55±0.019	94.6
Multiple regression for all soils: DTPA-extractable Cd on:			
Sludge Cd and % organic matter			96.3
Sludge Cd, % organic matter and % clay			96.8

TABLE A11. EXTRACTABLE Mo (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED AT 25°C FOR 42 AND 84 DAYS

Sludge[1]	Soil											
	St. Thomas		Vaudreuil		Grimsby		Haldimand		Rideau		Wendover	
	Incubation Period (days)											
	42	84	42	84	42	84	42	84	42	84	42	84
Acid ammonium oxalate												
No Sludge	0.13	0.02	0.04	0.11	0.15	0.14	0.35	0.36	0.36	0.03	0.29	0.33
Newmarket	0.78	1.44	0.79	1.22	1.22	1.64	0.95	2.0	1.10	1.46	0.60	1.38
Ottawa	1.32	2.04	0.88	1.23	2.02	1.70	1.75	1.9	1.10	0.94	0.72	1.42
Guelph	1.11	0.46	0.61	0.86	0.97	0.98	0.96	0.91	1.32	0.60	0.82	0.78
Stratford	17.3	16.1	12.4	13.4	18.0	20.8	11.6	18.8	11.7	19.4	12.5	14.0
$1N(NH_4)_2CO_3$												
No Sludge	0.06	0.06	0.07	0.06	0.04	0.04	0.13	0.11	0.06	0.05	0.19	0.19
Newmarket	2.12	1.91	1.96	2.10	1.48	1.48	1.26	1.40	0.61	1.58	2.12	2.20
Ottawa	0.67	1.41	1.63	2.50	1.56	1.41	1.92	1.67	1.01	1.55	0.88	1.92
Guelph	0.72	0.66	0.79	0.69	0.78	0.69	0.77	0.74	0.72	0.58	0.82	0.93
Stratford	21.0	15.0	11.0	21.7	19.0	20.8	13.8	18.8	14.5	19.3	16.7	20.7
0.02M KCl												
No Sludge	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.01	0.02	0.01	0.01
Newmarket	0.80	0.84	0.94	0.72	0.75	0.47	0.28	0.26	0.65	0.23	0.26	0.34
Ottawa	0.52	0.32	0.53	0.36	0.40	0.34	0.10	0.14	0.22	0.33	0.14	0.10
Guelph	0.19	0.22	0.15	0.23	0.19	0.21	0.04	0.03	0.12	0.12	0.04	0.04
Stratford	9.9	10.3	11.0	12.2	8.8	10.2	1.7	3.8	3.5	7.5	2.5	2.8

[1] The Newmarket, Ottawa and Guelph sludges added 1.9 µg Mo/g soil and the Stratford added 28.2 µg Mo/g soil.

TABLE A12. 0.005M DTPA-EXTRACTABLE METALS FROM GRIMSBY SILT LOAM SOIL TREATED WITH 2.5% SLUDGE AND INCUBATED UNDER A VARIETY OF SIMULATED FIELD CONDITIONS FOR 84 DAYS

Treatment	Sludge	pH	Metal[1] (µg/g soil)					
			Zn	Cu	Ni	Pb	Co	Cd
			Added in sludge					
	Ottawa		45	29	2.6	20.9	0.31	0.33
	Sarnia		262	21.2	0.73	82	0.17	2.5
			Extracted from soil					
25°C	No Sludge	4.1	1.9	1.4	0.23	0.80	0.25	0.12
	Ottawa	5.8	6.9	10.5	0.38	4.5	0.21	0.22
	Sarnia	5.4	54	7.8	0.23	14.6	0.27	1.20
10°C	No Sludge	4.1	1.7	1.1	0.30	0.92	0.26	0.09
	Ottawa	5.9	7.5	10.6	0.41	4.6	0.16	0.25
	Sarnia	5.8	52	8.0	0.25	15.0	0.20	1.37
-15°C	No Sludge	4.0	1.7	1.1	0.27	0.84	0.24	0.07
	Ottawa	6.0	8.6	7.7	0.49	4.7	0.15	0.24
	Sarnia	5.8	63	5.3	0.27	17.0	0.21	1.13
Alternate -15°C and 25°C	No Sludge	4.1	1.7	1.1	0.34	0.80	<0.15	0.08
	Ottawa	6.0	6.4	10.1	0.36	4.5	0.15	0.23
	Sarnia	5.9	47	7.5	0.26	15.3	0.21	1.37
50°C	No Sludge	4.4	0.64	1.2	0.20	0.74	0.27	0.25
	Ottawa	6.3	1.6	5.9	0.10	2.9	<0.15	0.25
	Sarnia	5.9	18.8	5.3	<0.10	8.1	0.15	1.24
25°C, Alternate Aerobic and Anaerobic	No Sludge	4.2	1.4	1.1	0.20	0.92	0.27	0.06
	Ottawa	6.2	4.3	9.6	0.29	5.0	<0.15	0.25
	Sarnia	5.9	35	7.3	0.29	15.0	0.26	1.27
25°C Anaerobic	No Sludge	4.2	1.7	1.1	0.24	0.96	0.27	0.07
	Ottawa	6.5	3.8	5.3	0.34	6.4	0.17	0.17
	Sarnia	6.1	28	3.3	0.16	16.4	0.22	0.74
25°C, pH 7	No Sludge	7.3	0.84	1.0	<0.10	0.73	<0.15	0.06
	Ottawa	7.3	5.2	12.2	0.15	5.4	0.18	0.25
	Sarnia	7.4	23.0	9.5	<0.10	17.6	<0.15	1.26
25°C, 10% $CaCO_3$	No Sludge	7.5	0.34	1.3	<0.10	0.73	0.15	0.08
	Ottawa	7.4	5.1	12.1	0.24	5.3	0.15	0.27
	Sarnia	7.3	25	8.7	<0.10	19.6	<0.15	1.35

[1] Sn and Cr were not detected in the extracts.

TABLE A13. 0.005M DTPA-EXTRACTABLE METALS FROM HALDIMAND SILTY CLAY LOAM SOIL TREATED WITH 2.5% SLUDGE AND INCUBATED UNDER A VARIETY OF SIMULATED FIELD CONDITIONS FOR 84 DAYS

Treatment	Sludge	pH	Metal[1] (µg/g soil)					
			Zn	Cu	Ni	Pb	Co	Cd
			Added in sludge					
	Ottawa		45	29	2.6	20.9	0.31	0.33
	Sarnia		262	21.2	0.73	82	0.17	2.5
			Extracted from soil					
25°C	No Sludge	4.7	2.0	1.5	0.70	2.3	0.19	0.11
	Ottawa	6.4	6.1	10.5	0.72	7.9	0.21	0.24
	Sarnia	5.9	45	8.4	0.52	19.8	0.22	1.24
10°C	No Sludge	4.6	1.6	1.3	0.71	2.5	0.25	0.15
	Ottawa	6.3	7.1	10.7	0.97	7.4	0.17	0.26
	Sarnia	6.1	47	7.6	0.61	21.3	0.21	1.26
-15°C	No Sludge	4.8	1.7	1.3	0.68	2.4	0.28	0.11
	Ottawa	6.2	7.5	7.2	1.03	6.9	0.25	0.25
	Sarnia	6.0	54	5.9	0.63	20.0	0.27	0.94
Alternate -15°C and 25°C	No Sludge	4.6	1.8	1.7	0.77	2.6	0.24	0.12
	Ottawa	6.3	5.8	11.7	0.85	7.3	0.18	0.27
	Sarnia	6.1	41	7.6	0.60	17.6	0.16	1.23
50°C	No Sludge	5.3	0.56	1.8	0.40	2.6	0.24	0.54
	Ottawa	6.7	1.8	6.4	0.35	5.6	0.32	0.41
	Sarnia	6.7	11.4	4.6	0.24	16.0	0.32	1.55
25°C, Alternate Aerobic and Anaerobic	No Sludge	5.1	2.0	1.7	0.75	2.6	0.44	0.14
	Ottawa	6.5	2.9	7.2	0.45	4.7	0.36	0.27
	Sarnia	6.3	18.9	4.8	0.35	8.8	0.44	1.07
25°C Anaerobic	No Sludge	6.2	0.40	1.1	0.23	0.32	0.33	0.08
	Ottawa	7.1	3.4	4.7	0.47	3.8	0.49	0.16
	Sarnia	6.7	24.0	3.3	0.32	4.7	0.41	0.65
25°C, pH 7	No Sludge	7.1	0.54	0.80	0.25	1.5	0.19	0.10
	Ottawa	7.2	5.4	12.0	0.67	7.9	0.28	0.29
	Sarnia	7.2	26	7.4	0.25	22.4	0.19	1.20
25°C, 10% $CaCO_3$	No Sludge	7.6	0.56	0.84	0.25	1.3	0.17	0.10
	Ottawa	7.3	5.2	11.8	0.58	7.4	0.23	0.29
	Sarnia	7.5	26	7.9	0.27	23.3	0.19	1.29

[1] Sn and Cr were not detected in the extracts.

TABLE A14. EXTRACTABLE Mo (µg/g soil) FROM SOILS TREATED WITH 2.5% SLUDGE AND INCUBATED UNDER A VARIETY OF SIMULATED FIELD CONDITIONS FOR 84 DAYS

Treatment	Sludge[1]	Soil					
		Grimsby			Haldimand		
		Extracting Reagent					
		Acid Ammonium Oxalate	1N $(NH_4)_2CO_3$	0.02M KCl	Acid Ammonium Oxalate	1N $(NH_4)_2CO_3$	0.02M KCl
-15°C	No Sludge	0.17	0.06	0.02	0.41	0.06	0.02
	Newmarket	1.94	0.96	0.98	2.04	1.33	0.18
	Ottawa	1.80	1.04	0.37	1.86	1.28	0.09
	Guelph	0.80	0.38	0.07	0.85	0.42	0.03
10°C	No Sludge	0.15	0.03	0.02	0.16	0.10	0.01
	Newmarket	2.70	1.04	1.08	1.62	0.97	0.18
	Ottawa	1.96	0.95	0.22	1.92	1.00	0.10
	Guelph	1.23	0.45	0.17	1.03	0.37	0.02
25°C	No Sludge	0.14	0.04	0.01	0.36	0.11	0.00
	Newmarket	1.64	1.48	0.47	2.00	1.40	0.26
	Ottawa	1.70	1.41	0.34	1.90	1.67	0.14
	Guelph	0.98	0.69	0.21	0.91	0.74	0.03
Alternate -15°C and 25°C	No Sludge	0.11	0.04	0.01	0.25	0.07	0.01
	Newmarket	2.32	1.08	NA	2.56	1.15	0.52
	Ottawa	1.44	1.15	0.72	2.34	1.01	0.14
	Guelph	0.78	0.38	0.23	0.92	0.38	0.05
25°C Alternate Aerobic and Anaerobic	No Sludge	0.13	0.03	0.01	0.32	0.09	0.00
	Newmarket	1.44	1.00	1.11	1.56	0.67	0.12
	Ottawa	1.56	0.96	0.64	1.68	0.61	0.07
	Guelph	0.67	0.43	0.14	0.82	0.34	0.08
25°C Anaerobic	No Sludge	0.14	0.04	0.00	0.41	0.18	0.03
	Newmarket	1.66	1.00	0.72	2.06	0.99	0.46
	Ottawa	1.56	1.27	0.52	1.46	0.90	0.26
	Guelph	0.56	0.41	0.14	1.14	0.48	0.10
25°C 10% $CaCO_3$	No Sludge	0.10	0.05	0.01	0.29	0.10	0.01
	Newmarket	1.64	1.46	0.57	1.36	1.16	0.24
	Ottawa	1.52	1.32	0.31	1.60	1.10	0.21
	Guelph	0.96	0.76	0.30	1.00	0.78	0.04

[1] The Newmarket, Ottawa and Guelph sludges each added 1.9 µg Mo/g soil.
NA = Not available.

TABLE A15. 0.005M DTPA-EXTRACTABLE METALS (µg/g soil) FROM SOILS TREATED WITH 2.5% INCREMENTS OF MIDLAND SLUDGE AT 42 DAY INTERVALS AND INCUBATED AT 25°C

Sludge Rate (%)	Metal Added to Soil (µg/g soil)		Soil					
			St. Thomas	Vaudreuil	Grimsby	Haldimand	Rideau	Wendover
			pH					
0			5.1	4.4	4.2	4.7	5.2	5.0
2.5			7.3	7.0	7.1	7.2	7.3	6.7
5.0			7.6	7.5	7.6	7.6	7.6	7.1
7.5			8.1	7.9	8.1	8.0	8.0	7.5
			Metals extracted from soil (µg/g soil)					
0	Zn	0	5.5	13.0	2.1	2.1	1.4	8.2
2.5		33	11.6	15.5	6.2	5.8	5.6	11.3
5.0		66	18.6	19.5	11.0	10.1	10.1	15.3
7.5		99	22.9	24.2	16.5	14.9	16.0	20.0
0	Cu	0	1.8	1.2	1.4	1.6	2.1	2.0
2.5		9.4	6.1	4.4	4.3	5.8	4.5	4.5
5.0		18.8	8.4	6.3	7.6	8.4	7.8	5.9
7.5		28.2	10.8	8.9	10.8	11.8	11.2	9.2
0	Ni	0	0.23	0.88	0.25	0.74	0.38	1.49
2.5		54	12.7	15.4	4.8	9.3	6.8	15.9
5.0		108	21.6	25	7.3	13.3	8.9	23.4
7.5		162	30	35	10.1	17.2	14.3	29
0	Pb	0	2.2	6.6	0.95	2.8	0.54	5.0
2.5		12.9	4.8	5.7	2.1	4.1	2.2	5.6
5.0		26	5.1	6.4	3.5	5.6	3.7	6.3
7.5		39	5.8	7.3	4.7	6.9	4.9	7.5
0	Cd	0	0.07	0.23	0.09	0.13	<0.05	0.23
2.5		0.01	0.08	0.22	0.11	0.13	0.06	0.23
5.0		0.02	0.13	0.23	0.11	0.16	0.10	0.23
7.5		0.03	0.20	0.26	0.16	0.14	0.19	0.32

TABLE A16. 0.005M DTPA-EXTRACTABLE METALS (µg/g soil) FROM SOILS TREATED WITH 2.5% INCREMENTS OF GUELPH SLUDGE AT 42 DAY INTERVALS AND INCUBATED AT 25°C

Sludge Rate (%)	Metal Added to Soil (µg/g soil)		Soil					
			St. Thomas	Vaudreuil	Grimsby	Haldimand	Rideau	Wendover
			pH					
0			5.1	4.4	4.2	4.7	5.2	5.0
2.5			6.3	5.8	5.4	5.9	6.4	5.6
5.0			6.7	6.2	6.3	6.5	6.9	5.9
7.5			6.2	6.0	6.2	6.4	6.7	5.8
			Metals extracted from soil (µg/g soil)					
0	Zn	0	5.5	13.0	2.1	2.1	1.4	8.2
2.5		176	73	101	58	51	39	83
5.0		352	126	174	104	105	75	155
7.5		528	192	234	142	135	113	200
0	Cu	0	1.8	1.2	1.4	1.6	2.1	2.0
2.5		87	33	30	34	32	27	30
5.0		174	58	56	51	58	45	58
7.5		261	93	87	79	81	64	77
0	Ni	0	0.23	0.88	0.25	0.74	0.38	1.49
2.5		3.4	1.22	1.95	0.97	1.28	0.80	2.9
5.0		6.8	1.85	3.1	1.00	1.96	1.06	2.9
7.5		10.2	2.6	3.6	1.03	2.6	1.29	3.6
0	Pb	0	2.2	6.6	0.95	2.8	0.54	5.0
2.5		41	9.8	12.1	8.7	12.6	9.4	11.9
5.0		82	16.8	17.1	12.9	20.3	17.8	16.6
7.5		123	26.0	23.6	20.2	25	24	13.6
0	Cd	0	0.07	0.23	0.09	0.13	<0.05	0.23
2.5		5.9	3.3	4.2	3.4	3.3	2.9	4.2
5.0		11.8	5.2	7.8	5.4	6.6	5.8	7.9
7.5		17.7	8.1	9.7	7.8	8.6	7.6	10.1

TABLE A17. 0.005M DTPA-EXTRACTABLE METALS (µg/g soil) FROM SOILS TREATED WITH 2.5% INCREMENTS OF FERGUS SLUDGE AT 42 DAY INTERVALS AND INCUBATED AT 25°C

Sludge Rate (%)	Metal Added to Soil (µg/g soil)		Soil					
			St. Thomas	Vaudreuil	Grimsby	Haldimand	Rideau	Wendover
			pH					
0			5.1	4.4	4.2	4.7	5.2	5.0
2.5			6.4	5.6	5.7	6.1	6.6	5.6
5.0			6.4	6.0	6.2	6.5	6.9	5.9
7.5			6.1	5.3	6.3	6.2	6.8	5.9
			Metals extracted from soil (µg/g soil)					
0	Zn	0	5.5	13.0	2.1	2.1	1.4	8.2
2.5		239	105	147	82	65	47	111
5.0		478	236	305	188	166	127	214
7.5		717	344	386	256	235	207	294
0	Cu	0	1.8	1.2	1.4	1.6	2.1	2.0
2.5		153	71	72	66	69	53	66
5.0		306	144	151	132	133	112	131
7.5		459	227	182	194	193	170	164
0	Ni	0	0.23	0.88	0.25	0.74	0.38	1.49
2.5		5.5	2.4	4.3	1.15	1.67	1.13	4.5
5.0		11.0	4.2	6.0	2.3	3.8	2.2	6.6
7.5		16.5	5.5	8.7	3.0	4.4	2.9	7.4
0	Pb	0	2.2	6.6	0.95	2.8	0.54	5.0
2.5		8.8	3.6	5.8	2.5	4.8	2.7	5.6
5.0		17.6	5.6	6.6	4.0	6.3	4.4	4.0
7.5		26.4	6.7	2.7	4.7	5.6	4.9	1.94
0	Cd	0	0.07	0.23	0.09	0.13	<0.05	0.23
2.5		0.58	0.45	0.65	0.44	0.51	0.39	0.70
5.0		1.16	0.86	1.13	0.85	0.97	0.73	1.11
7.5		1.74	1.18	1.41	1.08	1.27	1.07	1.47

TABLE A18. 0.005M DTPA-EXTRACTABLE METALS (µg/g soil) FROM SOILS TREATED WITH 2.5% INCREMENTS OF SARNIA SLUDGE AT 42 DAY INTERVALS AND INCUBATED AT 25°C

Sludge Rate (%)	Metal Added to Soil (µg/g soil)		Soil					
			St. Thomas	Vaudreuil	Grimsby	Haldimand	Rideau	Wendover
			pH					
0			5.1	4.4	4.2	4.7	5.2	5.0
2.5			6.3	5.7	5.4	5.9	6.3	5.6
5.0			6.7	6.1	6.1	6.3	6.6	5.9
7.5			6.8	6.4	6.6	6.6	7.0	6.1
			Metals extracted from soil (µg/g soil)					
0	Zn	0	5.5	13.0	2.1	2.1	1.4	8.2
2.5		262	74	114	54	45	34	83
5.0		524	145	165	93	85	66	124
7.5		786	230	209	125	115	93	153
0	Cu	0	1.8	1.2	1.4	1.6	2.1	2.0
2.5		21.2	8.7	7.6	7.8	8.4	6.6	7.6
5.0		42	15.7	13.1	14.9	15.4	12.7	11.6
7.5		63	22.5	17.3	20.6	20.6	17.8	14.9
0	Ni	0	0.23	0.88	0.25	0.74	0.38	1.49
2.5		0.73	0.31	0.83	0.24	0.52	0.25	1.43
5.0		1.46	0.46	1.12	0.21	0.53	0.36	1.49
7.5		2.2	0.55	1.11	0.33	0.63	0.44	1.46
0	Pb	0	2.2	6.6	0.95	2.8	0.54	5.0
2.5		82	16.8	15.3	15.1	20.7	18.3	15.5
5.0		164	34	20.7	31	37	38	20.5
7.5		246	52	26	45	48	49	33.1
0	Cd	0	0.07	0.23	0.09	0.13	<0.05	0.23
2.5		2.5	1.12	1.55	1.20	1.24	1.00	1.64
5.0		5.0	2.3	3.0	2.5	2.2	2.1	3.1
7.5		7.5	3.2	3.7	3.1	3.1	3.0	4.1

TABLE A19. 0.005M DTPA-EXTRACTABLE METALS (µg/g soil) FROM SOILS TREATED WITH 2.5% INCREMENTS OF SARNIA SLUDGE AT 42 DAY INTERVALS AND INCUBATED AT 50°C

Sludge Rate (%)	Metal Added to Soil (µg/g soil)		Soil					
			St. Thomas	Vaudreuil	Grimsby	Haldimand	Rideau	Wendover
			pH					
0			5.9	5.8	4.5	5.6	5.8	6.3
2.5			6.5	6.3	5.9	6.5	6.6	6.4
5.0			6.6	6.5	6.4	6.8	6.9	6.6
7.5			7.0	6.7	6.6	7.0	7.1	6.9
10			7.0	6.8	6.9	7.0	7.2	6.9
			Metals extracted from soil (µg/g soil)					
0	Zn	0	1.8	3.9	0.50	0.70	0.63	2.2
2.5		262	41	62	28	15.6	12.9	16.9
5.0		524	70	118	36	31	23.4	33
7.5		786	115	200	62	57	43	88
10		1048	134	229	81	82	58	123
0	Cu	0	1.1	1.2	0.77	1.2	0.98	2.0
2.5		21.2	5.6	6.8	5.6	4.0	3.6	5.9
5.0		42	8.3	9.0	7.6	6.0	7.1	7.6
7.5		63	13.8	14.3	12.5	13.6	13.3	12.8
10		84	14.7	13.8	15.1	16.4	16.4	12.4
0	Ni	0	<0.20	0.51	<0.20	0.33	0.20	0.59
2.5		0.73	0.22	0.50	<0.20	0.22	<0.20	0.56
5.0		1.46	0.22	0.47	<0.20	0.28	0.20	0.49
7.5		2.2	0.31	0.59	<0.20	0.29	0.22	0.60
10		2.9	0.28	0.59	<0.20	0.32	0.24	0.59
0	Pb	0	2.1	4.8	0.78	2.6	0.53	1.9
2.5		82	11.4	21.6	10.2	17.5	15.2	11.9
5.0		164	16.2	34	14.8	28	26	19.2
7.5		246	27	31	24	40	41	19.3
10		328	27	42	28	43	47	22.7
0	Cd	0	0.31	0.53	0.55	0.80	0.28	0.66
2.5		2.5	1.31	1.31	1.30	1.25	1.25	1.48
5.0		5.0	1.68	2.1	1.70	2.1	1.86	2.0
7.5		7.5	2.4	3.6	2.4	3.3	2.6	2.0
10		10.0	2.6	4.4	2.5	3.7	2.9	4.5

TABLE A20. Mo MOVEMENT THROUGH COLUMNS OF GRIMSBY SOIL LIMED TO pH 7, TREATED WITH SLUDGE AND LEACHED WITH 0.02M KCl

Column 1		Column 2	
Leachate Passed Through Column (cm)[1]	Cumulative Mo In Leachate (µg)	Leachate Passed Through Column (cm)[1]	Cumulative Mo In Leachate (µg)
No sludge			
72.4	6.3	85.4	9.9
129.3	10.6	152.2	15.2
221.6	17.3	248.6	22.9
336.6	18.1	376.0	23.5
Guelph sludge (added 62.7 µg Mo to column)			
97.4	11.3	77.3	33.7
156.0	13.0	135.8	36.3
251.7	16.9	230.2	37.6
341.2	18.3	315.6	40.1
Stratford sludge (added 931.4 µg Mo to column)			
75.1	143.9	68.9	125.0
129.8	263.2	130.2	278.1
222.8	657.4	223.8	588.2
319.9	897.1	303.0	813.6

[1] 68.73 cm leachate = 1 litre.

TABLE A21. Mo MOVEMENT THROUGH COLUMNS OF HALDIMAND SOIL LIMED TO pH 7, TREATED WITH SLUDGE AND LEACHED WITH 0.02M KCl

Column 1		Column 2	
Leachate Passed Through Column (cm)[1]	Cumulative Mo In Leachate (µg)	Leachate Passed Through Column (cm)[1]	Cumulative Mo In Leachate (µg)
No sludge			
41.3	1.2	17.6	0.3
61.3	1.6	41.2	1.1
72.2	1.8	56.6	1.4
87.9	2.1	72.6	1.6
101.7	2.3	81.5	1.8
109.6	3.4	87.7	1.9
124.7	3.6	94.4	2.4
		110.3	2.5
Guelph sludge (added 31.4 µg Mo to column)			
32.7	2.0	12.4	1.3
47.2	2.4	28.3	4.8
68.4	3.2	40.8	6.6
79.1	4.7	51.2	6.9
87.9	5.6	69.7	7.7
96.1	6.1	85.3	10.2
101.1	7.1	95.8	10.8
118.6	7.9	105.1	11.6
		123.9	11.9
Stratford sludge (added 465.7 µg Mo to column)			
13.8	13.7	8.0	0.9
26.5	35.8	20.1	21.3
37.0	59.9	32.9	103.3
54.9	116.6	43.2	145.1
64.7	150.7	49.5	159.6
69.6	161.3	58.2	179.8
78.1	169.7	68.8	202.5
83.5	173.5	83.4	245.1
103.5	196.8		

[1] 68.73 cm leachate = 1 litre.

TABLE A22. Mo MOVEMENT THROUGH COLUMNS OF WENDOVER SOIL LIMED TO pH 7, TREATED WITH SLUDGE AND LEACHED WITH 0.02M KCl

Column 1		Column 2	
Leachate Passed Through Column (cm)[1]	Cumulative Mo In Leachate (µg)	Leachate Passed Through Column (cm)[1]	Cumulative Mo In Leachate (µg)
No sludge			
32.5	1.8	24.8	1.1
49.4	3.1	49.4	2.6
75.1	4.2	104.4	4.9
99.2	5.1	117.9	5.1
129.5	6.3	141.9	5.4
184.3	10.7	179.9	5.7
328.5	14.0	219.8	6.3
		322.1	7.4
		403.9	9.0
Guelph sludge (added 62.7 µg Mo to column)			
13.4	1.2	14.1	1.7
22.7	1.6	34.4	3.0
37.2	2.1	58.1	7.1
63.6	5.3	83.9	9.4
91.0	6.5	109.9	10.8
119.4	9.6	178.8	13.3
177.3	14.1	252.1	16.3
259.2	18.1		
Stratford sludge (added 931.4 µg Mo to column)			
31.9	11.2	10.6	1.9
52.7	23.7	22.1	5.2
66.7	42.5	34.5	28.0
92.9	79.7	64.1	113.1
119.6	113.8	81.8	168.9
147.3	154.6	106.1	239.4
251.3	170.0	163.9	254.4
345.7	181.8	247.6	267.5

[1] 68.73 cm leachate = 1 litre.

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